The Effect of Endogenous Auditory Cue-Target Congruency on Upper Limb Rapid Reaching Trajectories.

by

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Abstract

We are constantly faced with multiple opportunities for action requiring decision making and performance at a given moment during our daily activities. These decisions range from simple choices made without conscious deliberation or attention to the more voluntary and conscious choices. It is therefore essential that individuals assess their environments and respond in effective ways. To understand how individual's use multisensory cues to assess their environment and respond effectively, this study assessed the effect of congruency of endogenous auditory stimuli on reaching performance to multiple targets.

Twelve right-handed individuals engaged in a rapid, multi-target reaching task towards a touch screen monitor. Three endogenous auditory cue conditions (no-sound, valid and invalid) were randomised. An Optotrak 3D Investigator (NDI) was used to measure reach trajectories at a collection frame frequency of 500Hz. Participants were instructed to reach and touch the indicated target as quickly and accurately as possible. Statistical analysis was performed on the kinematic data at two movement onset thresholds (30mm/s and 15mm/s), and significance was set at $p < .05$.

Results from the 30mm/s kinematic threshold data showed that reaction time (RT) was significantly shorter in the valid condition as opposed to the no-sound condition [$F(2, 20)= 3.519$, $p<0.05$] and participants performed similarly on movement time (MT) in all conditions [$F(2, 20)= 1.527$, $p>0.05$]. In contrast, the results from the analysis using 15mm/s threshold revealed that RT in all three conditions was statistically insignificant [$F (2, 18) = 0.228$, $p>0.05$] and movement time in the valid condition was statistically significantly longer than the No-sound condition [$F (2, 18) = 5.222$, $p = 0.016$]. In both analyses, the trajectory analysis revealed that the percentage of time to peak velocity was longer when reaching to upper targets. Movement trajectory deviations became significant between upper and lower targets at 60% of movement regardless of condition. Our results showed that endogenous auditory cues presented concurrently with the movement target location had no impact on reaction time. However, there was a negative impact on MT that was reflected in the longer movement times observed in the valid and invalid conditions as opposed to the no-sound condition.

Keywords: endogenous attention, goal-directed aiming, multiple targets aiming, movement trajectory.

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Chapter One

Introduction

When considering human consciousness, an essential aspect of human cognition, perception and motor performance is the concept of attention (James, 1890; Oladokun, 2017; Schmidt and Lee, 2019). Each day we are faced with multiple opportunities for action requiring ongoing decision making and performance at a given moment. These decisions range from simple choices made without conscious deliberation or attention to the more voluntary and conscious choices. For example, consciously deciding to take the stairs instead of an elevator compared to the seemingly automatic choice of reaching the snooze button on our morning alarm as it blares. It is essential that individuals voluntarily assess their environments and respond in effective ways as reflected in the early definition of attention as “the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or train of thoughts.” (James, 1890). Conventionally, attention has also been defined as the optimal utilisation of limited capacities to process, store, and retrieve information via some set of cognitive/neural mechanisms (Hommel et al., 2019). These definitions highlight a limitation in the capacity for information processing, meaning that the brain has to make decisions while dealing with various competing sensory information at different times.

A popular example is the cocktail party effect originally coined by Colin Cherry in his 1953 paper, whereby an individual selectively focuses attention on one auditory stimulus while filtering out other competing stimuli (Bronkhorst, 2015). However, if a salient stimulus becomes present such as your name, suddenly the individual becomes aware of that other competing stimulus (e.g., the other conversation occurring in the room). The cocktail party phenomenon shows that unattended stimuli, or in this case speech, is processed semantically even when it is not available to conscious recollection (Bentin, Kutas, & Hillyard, 1995). Over the years, researchers have tried to understand how the presence of these additional stimuli affects attentional capacity and our ability to generate appropriate motor responses (Chapman, Gallivan, Wood, Milne, Culham, & Goodale, 2010; Cisek & Kalaska, 2005; M Ray, Weeks, & Welsh, 2014; S. P. Tipper et al., 1998; Welsh & Elliott, 2004). For example, how we respond when reaching out to a glass of water and then noticing the phone ringing during the process. Our response may be to immediately change directions to reach for the phone without prior intentions to reach in that direction. What were the processes that happened for the sound to capture our attention and subsequently change the limb coordination appropriately to reach out to the phone instead of the glass of water as initially intended? Did the phone's sudden sound compete with the brain's limited information processing ability? These are some of the questions about attention that researchers have tried to understand in past studies, some of which will be highlighted in the literature review section below. The type of attention described above is referred to as covert attention. Covert attention is described by James (1890) as the ability for sensory stimuli perceived to invoke an action to attend to a location voluntarily or reflexively. It can also be captured by abrupt or unexpected stimuli in our environment (Posner, Walker, Friedrich, & Rafal, 1987).

Posner (1980) used a cue-target paradigm and conceptualized covert attention as being endogenous (voluntarily control of our attention by consciously monitoring information at a location) and exogenous (also called transient or reflexive attention because there is an automatic orientation response when a stimulus occurs suddenly). This paradigm is now referred to as the "Posnerian paradigm" (Chica & Lupiáñez, 2009; Jones & Forster, 2014). The Posnerian paradigm required participants to respond as fast as possible to a target that may or may not appear at a cued location. The participants focused on a fixation point before the appearance of an exogenous or endogenous cue. In the endogenous condition, participants were cued to voluntarily direct their covert attention to the cued side by the appearance of an arrow as a visual cue which indicated the likely position of the target. The exogenous condition provided a non-predictive cue at peripheral locations, which may or may not be the same location as the target location. Regardless of cue type, a faster response time was recorded for the participants when the target appeared at the same location as the initial cued location (Posner, 1980).

Exogenous and endogenous cues can also occur across modalities (Spence & Driver, 1994) whereby different stimuli can capture attention towards or away from a primary stimulus in another modality. An example is the scenario mentioned above where someone is reaching for a glass of water, and the phone starts ringing. This cross-modal interaction (having a stimulus from one sense affect the other stimulus from another sense either negatively or positively) is thought to occur at a multisensory integration level (whereby the two stimuli combine to produce a result) which impacts decision making by considering relevant spatial and temporal congruent information in the environment. Chapman et al. 2010 developed a paradigm in his series of experiments which showed that when participants were uncertain about the location of a targets amongst multiple potential targets, they made use of spatial averaging whereby participants reached towards an averaged location before correcting their movement trajectory in flight to the cued target location. Additionally, Oladokun et al 2017 showed that exogenous auditory cues have the potential to enhance reach performance when reaching to multiple targets. While endogenous visual cues benefit performance, the role of endogenous auditory cues in multi-target aiming is poorly understood. Therefore, the current experiment seeks to explore the coupling of attention and action by measuring the influence endogenous auditory cues have on movement planning and execution. This study uses a spatial-averaging paradigm and seeks to answer the question of how participants use the available information in the form of auditory cueing presented after movement initiation to plan and execute their movement to an unknown target location and to understand its influence on unfolding decision making.

Chapter Two

Literature Review

Attention

“Everyone knows what attention is” (James, 1890) is one of the most popular quotes and perhaps the most famous statement about human attention (Hommel et al., 2019). Attention is thought to be limited in that we can only attend to one thing at a time. Hence, attention has been conventionally defined as the optimal utilization of limited capacities to process, store, and retrieve information via some set of cognitive/ neural mechanisms (Hommel et al., 2019). Attention is also attributed to having a selective feature because we can freely shift our attention from one task or event to another. According to Wulf, Vance, Tollner, McNevin, and Mercer (2013), attentional focus has been characterized in various numerous ways in terms of directions (internal vs external), width (broad vs narrow), associative (when the focus is on bodily sensation) and dissociative (when the sensation from physical efforts is blocked out). In subsequent paragraphs, we will briefly review some of the early theories of attention.

From the definition of attention, it can be said that attention is measured by the degree of task interference caused by the limitation in attentional capacity when performing two or more tasks. However, not all tasks interfere with attentional processing. The time it takes to perform a task involves two stages, reaction time and the actual movement time. Reaction time (RT) is defined as the time between the presentation of a stimulus and the start of movement initiation or the beginning of a response. RT consists of three stages which are stimulus identification, response selection and movement programming stage. Hence the interference effect on information processing caused by limited attention capacity can happen within any stage during an individual’s reaction time. With the use of hypothetical structures and processes, different theories have tried to explain patterns of interference that limit human attention.

One of such theory is the single-channel theory also known as bottleneck theory, which assumes that when an individual is faced with more than one task, the series of information is processed in parallel, but at some point, the information converges at a central decision channel of limited capacity which then causes a filter to block irrelevant messages before they arrive at a bottleneck, thus allowing attention to be directed to one task at a time (Broadbent, 1958; Treisman, 1969). However, a problem with this theory is at what position/location does one encounter this bottleneck during the movement planning and execution? This question of the location of the bottleneck was further explored by different researchers such as Welford (1952), who placed the filter at the earlier stages of information processing. Deutsch & Deutsch, (1963) hypothesized that the bottleneck was somewhere around the middle stages, while Keele (1973) hypothesized the location occurs later after the response selection stage. Other theories of attention include those that believe that attention comes from multiple pools of resources used for information processing rather than having a single channel (Wickens and McCarley 2008, Wickens & Holland 2000). In this theory, when participating in multiple tasks different resources are devoted to completing each type of task. Thus, multiple pools of attention can be an explanation for why we can carry out multiple tasks such as pointing and reading or speaking at the same time without conflicting interference occurring.

Another theory of attention which takes an ecological standpoint is the action-selection view on attention. Researchers such as Neumann 1987, assumed that attention to one task is the byproduct of intentionally selecting a goal to complete a particular task; hence all other competing stimuli will initially be processed in parallel, but because a selection has already been made, the processing of the other stimuli comes to a halt or is blocked in order to allow the completion of the selected task to occur. This theory also confirms the limited capacity on the attentional system whereby some form of information processing had to be suspended, thus interfering with the process in order for the selected task to be completed.

From the above, we can see that attention can be defined and applied to a wide variety of phenomena. Depending on the context, attention has been described and categorized as mental concentration, vigilance, activations, selective attention, and search (Moray, 1969). For the sake of this review, we will be examining selective attention and more specifically, covert auditory attention.

Attention as a selective process

According to Treisman (1969), attention is the selective aspect of perception and associated responses. An early exploration of this idea was done by Helmholtz in 1867 by using a classic pinhole experiment that showed that humans could selectively attend to one location without eye movements. Helmholtz (1867) observed that after letters were lit for a fraction of a second, he could perceive letters in certain regions away from the location he fixed his gaze on. Selectively attending to an object or location while ignoring other stimuli has been attributed to the limitation in the human capacity to hold and process excessive information because of the notion that stimuli compete for a limited amount of attentional or processing resources (Treisman, 1969; Schmidt and Lee, 2019). This limit in resources is likely due to a fixed amount of energy available to the brain and by the high-energy cost of the neuronal activity involved in cortical computation (Attwell & Laughlin, 2001; Carrasco, 2011). The implication of this limitation is that specific neural pathways are activated while others are suppressed in order to efficiently complete a task. Evidence of this neural competition has been shown using multiple stimuli that are presented sequentially or simultaneously while being positioned within proximity or at a distance to each other and then asking participants to fix their gaze at a particular location. Results from several studies provide evidence that simultaneous presentations of stimuli evoke reduced neural responses than sequential stimuli presentation (Beck & Kastner, 2005, 2007; Kastner et al., 2001; Matthew Ray, Weeks, & Welsh, 2014; Recanzone & Wurtz, 2000; Reynolds, Chelazzi, & Desimone, 1999; Snowden et al., 1991). Beck & Kastner (2007) experiment supports this notion whereby using fMRI, it was found that there was substantial suppressive interaction in certain neuronal regions of the brain when four objects were presented simultaneously (potentially competing) as opposed to when presented sequentially (non-competing) and that these reductions in neuronal activity were most pronounced when the objects were identical in colour and orientation as opposed to when the items were clearly different. Hence, when multiple stimuli are presented at the same time, the stimuli compete for neural representation.

This is now referred to as the biased competition theory of selective attention. This theory of attention proposes that the competitive interactions among multiple stimuli can be influenced by both top-down selective attention and by bottom-up stimulus-driven processes, such as visual salience (Beck & Kastner, 2005, 2007; Recanzone & Wurtz, 2000; Reynolds et al., 1999). Support for this theory comes from behavioural studies focusing on spatial attention and its importance in navigating complex environments (Beck & Kastner, 2005, 2007). These studies report a loss in spatial resolution and processing efficiency when attention is spread over a large visual field area as opposed to being focused on one location or given sub-region of the visual field (Castiello & Umilta, 1990; Eriksen & Murphy, 1987). For example, the study by Kirsch & Kunde, 2021 showed that the size of attended spatial area affected the perceived location of an object with a significant decrease in the perceived location of an object following an increase in spatial areas attended to.

In conclusion, in order to optimize performance, attention utilizes limited neuronal resources by enhancing the representation of the most relevant stimuli or information while diminishing the representation of competing stimuli in the environment. Thus, selective attention helps guide our behaviour by enabling us to gather the most relevant information in our environment (Carrasco 2011).

Overt and covert attention

The focus of spatial attention has been likened to a spotlight (Posner, 1980), a zoom lens (Eriksen & Yeh, 1985), or a Gaussian gradient (Downing & Pinker, 1985) that enhances the processing of visual stimuli within a circumscribed region of space (Carrasco, 2011). Spatial orienting refers to adjustments that improve the processing of stimuli coming from a location in space or that improve their access to response mechanisms (Posner, 1980). The use of spatial attention involves orienting one’s attention in space based on cues or expectancies from prior experience (Madrid, Robbins, Scarince, Godwin, & Hout, 2016). Attention can be oriented in two main ways: Overtly and covertly. Overt attention occurs when the eyes, head, or body (or a combination of two or three of these) are moved to visually direct one's attention to an event or object of interest. For example, visually looking for road signs as one drives down a street. This means that overt attention is directed to one location or event at a time, hence it occurs sequentially. Covert attention in contrast, refers to the direction of one's attention to an area in the visual field without the area falling under the direct fixation of the eyes. This type of attention is often referred to as environmental monitoring and is accomplished without shifting one’s gaze. However, it should be noted that the information gained can inform subsequent eye movements. Thus, covert attention allows the possibility of analyzing simultaneous locations or events before visually focusing on one. In this way, covert attention can precede overt attention. The latter strategy is adopted when completing a variety of tasks throughout the day. For example, visually focusing forward (keeping one's eyes on the road) while also scanning the road for pedestrians as one drives. We now know that humans can voluntarily initiate covert attention in the absence of concurrent eye movements. It is also important to consider visually cueing participants to a consistent fixation point when designing studies testing attention so as to discourage attention from remaining at a previously cued location. In terms of temporal differences between the two types of covert attention, exogenous attention (occurring due to sudden change in the environment) is thought to be phylogenetically older (Carrasco & Barbot, 2018) due to its ability to cause individuals to interact with the environment faster than endogenous attention (guided by higher cognitive functions). Endogenous cues have a characteristic reaction time of about 300ms (Spence & Driver, 1994). The additional time is needed to provide an allowance for individuals to voluntarily direct their attention to engage with the environment. (Spence & Driver, 1994). In contrast, exogenous attention tends to peak at about 200ms, after which a decay follows (Spence and Driver, 1994), commonly referred to as an “inhibition of return”; whereby movements to a target have longer reaction times when the target is in the same location that the non-informative cue occurred (Posner and Cohen, 1984).

Covert Spatial Attention - Exogenous and endogenous attention

When navigating and interacting with the environment, both overt and covert spatial attention is important. For instance, spatial attention can be influenced by salient features of our environment using bottom-up processing. Here, attention is sometimes captured by the sudden onset of motion, sound, or changes in light and colours that alert us to changes in our environment. In contrast, spatial attention can also be driven primarily by top-down processing. For example, conducting a visual search to find an item we are looking for. Hence, the basic visual features of the item or event draw our attention when the features match what we are looking for. Evidence from behavioural studies demonstrates two types of covert attention. The first, endogenous attention (also called voluntary, goal-directed or top-down guidance), is when attention is guided by higher cognitive functions, such as our goals, motivations, and expectancies (Macaluso, 2010; Macaluso & Doricchi, 2013) . For example, imagine reaching into the fridge to get a box of juice. We already know the physical features of this juice box; perhaps we also have a particular location in the fridge where we store juice boxes; hence, we are immediately oriented to attend to that location. However, imagine we were trying to get a juice box from an unfamiliar fridge belonging to a friend and suddenly a bottle of milk falls off the door of the fridge. Here, we would be making use of “exogenous” attention (also called bottom-up attention), which is involuntary or stimulus-driven attention. Exogenous attention corresponds to an automatic orienting response to a location where salient or sudden sensory events have occurred (Hopfinger & West, 2006).

The extensive study of covert visual attention using the cueing paradigm proposed by Posner (1980) have raised some distinct differences between exogenous and endogenous orienting mechanisms. The cueing paradigm used by Posner tested centrally located cues that provided information about the subsequent target location (endogenous orienting) facilitated performance. However, cues presented peripherally that contained no information about subsequent target location (exogenous orienting) produced facilitation to targets occurring at the cued location provided there was a short cue-target stimulus-onset asynchronies (SOAs) of less than 300ms.

These same cues also showed inhibitory effects at longer SOAs, an effect known as inhibition of return (IOR). IOR is thought to help maximize sampling of visual information and facilitate foraging (Klein & Ivanoff, 2008). Exogenous attention takes place automatically, with attention pulled to the location of salient cues. Endogenous attention is directed or pushed towards a location where a target is expected to appear. Another distinguishing difference is that secondary verbal memory tasks do not disrupt performance of exogenous orienting, whereas verbal memory tasks do interfere during endogenous orienting tasks (Jonides, 1981). Muller & Rabbitt (1989) explained the reason for this difference is that endogenous orienting of the central symbolic cues must first be decoded before the spatial location that the cue designates can be determined. On the other hand, for exogenous orienting, peripheral cues convey spatial information directly because they occur at the locations at which the subsequent target signals are likely to be presented. Thus, it follows that a secondary memory load may interfere with the processing of endogenous attention more than exogenous attention.

Exogenous attention has also been reported to be biphasic in nature, meaning that it can exhibit both facilitatory and inhibitory effects on performance (Hanlon et al., 2017; Klein & Ivanoff, 2008; Neyedli & Welsh, 2012). If a target stimulus appears near the cued location within about 200ms of cue onset, detection, discrimination, and localization responses are facilitated relative to responses to targets presented elsewhere in the display. The initial benefit following an uninformative cue presented before the target reverses to become a disadvantage at longer delays between the presentation of the cue and presentation of target (i.e., stimulus onset asynchrony (SOA)). This disadvantage phenomenon known as “inhibition of return” begins to occur after over 300ms SOA, whereby attention is summoned to the cued location and then moved to a new location. Returning attention to the cued location is then slower than an uncued location (Hanlon et al., 2017; Klein & Ivanoff, 2008; Neyedli & Welsh, 2012). In contrast, facilitatory effects for endogenous orienting reaches a maximum capacity at SOA greater than 250-300ms and remains relatively stable (Muller & Rabbitt, 1989). According to Muller & Rabbitt, (1989), the differences in the time course of facilitatory and inhibitory effects produced by peripheral (exogenous) cues is because peripheral cues trigger both a fast-acting reflexive (automatic) and a slower-acting voluntary (controlled) orienting mechanisms. The rapid automatic mechanism has a powerful but transitory response that fades about 100-300 ms after cue onset. The voluntary/controlled orienting mechanism has a longer rise time and is less effective but also shows a longer persistence. In other words, central (endogenous) cues initiate only the voluntary orienting mechanism.

Neural evidence

The neural components of attention are quite vast. Attention is thought to be a combination of multiple cognitive processes working together to complete tasks (Posner & Petersen, 1990). Therefore, attention requires the integration of different neural components from basic sensation to higher-order decision-making and executive control (Petersen & Posner, 2012). According to Posner & Petersen (1990), three networks were involved in the neural processing of attention. The classifications were based on behavioural studies of normal adults or patients with varying forms of brain injury (Petersen and Posner, 2012). The first proposed network is the alerting network, which focuses on brainstem arousal systems along with right hemisphere systems related to sustained vigilance. The second proposed network is an orienting network that, among other regions, is thought to be based in the parietal cortex. Finally, the executive network includes the midline frontal/anterior cingulate cortex. Findings suggest that endogenous orienting activates a larger cortical network to achieve internally generated shifts of attentional resources versus the automatic orienting that occurs with exogenous cues (Mayer, Dorflinger, Rao, & Seidenberg, 2004). Through research, two robust lines of evidence have been studied. The first studies done in the 1980’s before the advent of functional neuroimaging (fMRI), in patients with midbrain and cortical damage. Here, patients with progressive supranuclear palsy (PSP) were presented with a central or peripheral cue indicating the likely location of a target. The purpose of the task was to cause a movement of attention in the direction of the cued location. Exogenous spatial orientation was found to be slow (Posner, Cohen, & Rafal, 1982; Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988). This line of evidence was based on the fact that cells in the superior colliculi that are impaired in PSP respond reflexively to exogenous orientation but are suppressed with endogenous orientation (Robinson & Kertzman, 1995). On the other hand, patients with lesions to the temporoparietal junction (TPJ), and the superior and inferior parietal lobes (Posner et al., 1987) are typically impaired engaging endogenous, but not exogenous, cues. Other areas that are thought to be important in endogenous cueing include the frontal eye field (Henik, Rafal, & Rhodes, 1994) and intraparietal sulcus (Robinson, Bowman, & Kertzman, 1995)

The second line of evidence comes from more recent research from fMRI studies that have also demonstrated the activation of intraparietal sulcus and frontal eye field with endogenous attentional cues and TPJ and inferior frontal gyrus with stimulus-driven attention orientation (exogenous cues). For example, Kincade, Abrams, Astafiev, Shulman, & Corbetta, 2005 measured the effect of endogenous and exogenous attention on blood oxygenation level-dependent signal in humans by separating activities related to initial attentional shift from activities caused by target presentation. The authors found activation in the dorsal frontoparietal attention region, bilateral frontal eye field, intraparietal sulcus, occipital lobe and the right temporoparietal junction (TPJ) with endogenous cues, while exogenous cues resulted in activations in the occipitotemporal regions, ventral frontoparietal region and less activations in the TPJ. These results are also similar to reports by Mayer et al. (2004).

Covert spatial auditory attention

Inspired by covert visual attention studies, covert auditory attention studies using cue-target paradigms have produced conflicting results. For example, Scharf, Quigley, Aoki, Peachey, & Reeves (1987) reported no significant change to response latency (reaction time) to sound targets under an expected and unexpected sound conditions. Similarly, (Buchtel & Butter, 1988) measured participant’s reaction time to visual and auditory targets in the presence of visual and auditory cues. They reported improved reaction time when the target was visual and with auditory cueing, but no effect in latency to an auditory target even in the presence of auditory cueing. The authors concluded that auditory cueing had a general alerting effect which positively influenced response latency to visual targets. This was explored further with neutral/uninformative cues that showed auditory detection was not modulated by visual cues. This result is similar to that of Klein, Brennan, and Gilani, (1987), where reaction time (RT) to luminance targets was found to be affected by a non-informative auditory event, suggesting that localizable auditory stimuli rapidly and automatically capture visual attention and thus have an alerting effect.

Posner (1978) speculated that participants might be insensitive to auditory spatial attention due to sound localization occurring later than auditory detection. The location of a sound source needs to be computed on the basis of differences between the ears in phase, intensity, or frequency spectrum of the sound by specialized, location-sensitive neurons in more central brain areas, such as the superior olives, inferior and superior colliculi, or auditory cortices, (Rhodes, 1987; Spence & Driver, 1994). To account for the insensitivity of auditory spatial attention, McDonald & Ward (1999) proposed the spatial relevance hypothesis (SRH). The SRH states that covert auditory spatial orienting can only be beneficial to auditory processing when task stimuli are encoded spatially because location-sensitive neuron activation is necessary for spatial orienting to be beneficial in audition. However, these location-sensitive neurons are not always engaged. This proposal was born out of McDonald and Ward's (1999) series of experiments conducted to determine the precise conditions under which exogenous covert orienting and IOR occur in audition. In some experiments, an implicit spatial discrimination paradigm was implored whereby the decision to respond was based on the spatial location of the target. In other experiments, the spatial location of the auditory targets was not directly relevant to the task, and the decision to respond was based on non-spatial criteria. They also tested space relevance in a non-spatial task by using spatially informative cues to know if spatial cue effects would occur even though the response was based on non-spatial criteria. The results showed that auditory spatial cues influenced response latencies in spatial tasks but not in non-spatial tasks unless spatial relevance was established for the non-spatial task. Thus, the use of spatial coding is critical to performance on spatial-discrimination tasks whereby listeners are motivated to encode the task stimuli spatially in order to expect benefits when the cues are informative about the target location. In contrast, cues that are uninformative about target location would not be expected to result in spatial coding of task stimuli and would therefore not lead to any spatial-orienting benefits. (McDonald & Ward, 1999; Roberts, Summerfield, & Hall, 2009). Two conditions of SRH under which spatial orienting benefits can be observed using auditory cueing are (a) “any task constraint that makes space important for the listener will produce auditory spatial-cue effects” and (b) “reflexive activation of location sensitive neurons is not sufficient to produce attentional facilitation” (McDonald & Ward, 1999, p. 1236). Roberts et al. (2009) decided to evaluate these conditions in their studies by addressing the role of spatial orienting in non-spatial tasks. The results obtained in the series of experiments done contradict the claim that reflexive orienting cannot facilitate performance on non-spatial tasks. However, their results support the notion that spatial-orienting benefits can be obtained when space is relevant to the task.

Multisensory integration

Humans are bombarded with large amounts of sensory input daily. The various sensory inputs are needed to interact and function optimally within the environment. In many cases, effective sensory integration is important to our survival. Multisensory integration (MSI) is defined as the process through which information from independent but temporally aligned signals/stimulus derived from multiple sensory sources (e.g., vision, auditory) are combined by the brain into coherent representations (Marucci et al., 2021). The ability to use cues from multiple senses is a fundamental aspect of the central nervous system function as multisensory information at a given moment enhances the physiological salience of external events which results in computational benefits that cannot be achieved from unisensory stimuli (Stein, Stanford, & Rowland, 2014). Hence, multisensory integration not only has substantial survival value but can also create unique experiences that emerge when signals from different sensory channels are integrated together (Stein et al., 2014).

Behavioural studies have provided evidence that one of the outcomes of multisensory integration (MSI) is reduced time required for motor planning (Colonius & Diederich, 2004; Diederich & Colonius, 2015; Glazebrook, Welsh, & Tremblay, 2016). According to many studies, multimodal stimuli induce faster and more accurate responses than the summed probability of two unisensory stimuli (Colonius & Diederich, 2004; Lunn, Sjoblom, Ward, Soto-Faraco, & Forster, 2019; B. E. Stein, Meredith, Huneycutt, & McDade, 1989). However, for MSI to occur, unimodal stimuli are required to be spatiotemporally congruent (Colonius, Diederich, & Steenken, 2009). For example, Stein and colleagues in their 1989 study, trained cats to fixate directly on a point and then to orient overtly towards a sudden visual target in order to receive a reward. Their results showed that orienting was significantly more accurate when the visual stimulus was accompanied by a spatially coincident sound relative to when the visual stimulus was presented. Similarly, Glazebrook et al. (2016) also reported stimuli integration when participants were required to reach to a visual or an auditory target. Participants were told to ignore the secondary stimulus (visual or auditory) presented coincidently. However, the visual cue influenced motor planning of responses toward auditory targets with evidence of early online control to the auditory target when a secondary visual stimulus was presented. The authors also reported more accurate movements to the visual targets.

In order to explain the effect of spatiotemporal congruency between the unimodal stimuli causing favorable outcomes, Colonius & Diederich (2004) proposed a model explaining the process of MSI called the time window for integration model (TWIN model). This model postulates two stages responsible for the advantages reported with MSI. The first stage involves a race mechanism whereby cross-modal/audiovisual stimulus triggers the peripheral sensory pathways, followed by the second stage involving the process of neural integration of the stimulus in preparation for a response. Hence, a central assumption to the TWIN model is that the first stage involving the race mechanism between the unimodal stimuli must all terminate within a given temporal interval which acts as a window to determine whether the information delivered from the different sensory organs is registered close enough in time to trigger multisensory integration (Diederich & Colonius, 2015).

Through multisensory integration, multisensory stimuli have been proposed to effectively capture attention because of the faster and more accurate response elicited (Santangelo & Spence, 2007; Stein et al., 1989). The ability of multisensory stimuli to capture attention has been thought to be beneficial whereby causing desirable behavioural effects like movement facilitation. MSI can also be disruptive whereby causing a distraction that pulls attention away from the task being done. Previous work showed that the facilitation effects of multisensory integration on attentional capture towards target detection seem to rely on the stimuli to be attended and that perceptual load (defined as the amount of information involved in the processing of the task stimuli) influences outcomes (Santangelo & Spence, 2007; Talsma, Doty, & Woldorff, 2007). Therefore, this has led to the assumption that multisensory integration processes occur either prior to or independent of the allocation of attention.

Lunn et al. (2019) examined how the notion of multisensory enhancement of attention conflicts with findings suggesting that multisensory integration may be dependent upon endogenous attention. During the study, facilitation and distraction were used to modulate attentional capture in order to vary reliance on endogenous attention. The authors also manipulated the degree of perceptual load in order to determine whether multisensory stimuli were able to capture attention when performing another primary task. The results obtained showed that detection of multisensory stimuli presented as search targets was faster than unisensory stimuli, regardless of perceptual load (Lunn et al., 2019). The latter findings are also similar to results obtained by Santangelo & Spence (2007). The results also showed that task irrelevant multisensory stimuli (distracters) did not cause greater distraction than unisensory stimuli, suggesting that the enhanced attentional status of multisensory stimuli may be mediated by the availability of endogenous attention (Lunn et al., 2019). Therefore, multisensory stimuli could be useful during high load tasks by serving as alerting systems.

Studies investigating the neural mechanism of MSI show increased activity in the superior temporal sulcus, superior colliculus, primary visual and auditory cortices, superior temporal sulcus, and intraparietal area (Meredith, Nemitz, & Stein, 1987; Stein et al., 2014). These cortical neural activations are similar to the cortical activation process of attention, which further suggests an interaction between attention and multisensory integration.

Goal-directed movement

According to Henry and Rogers (1960), additional neural processes are required when there is an increase in the complexity of the required response. They compared different complex movements as opposed to simple movements in a simple RT task. The additional neural processing manifests as an increase in movement preparation time, also known as reaction time (RT). The more complex responses also led to increased execution time of the task, referred to as movement time (MT). Reaction time according to Schmidt and Lee (2010), is a measure of the time from the presentation of an unanticipated signal to the beginning of a response to the signal. RT can be partitioned into two stages. A central processing stage termed the premotor RT, whereby the muscle is activated late during the reaction time interval to allow for the brain to process making a response such as perception and decision. The second stage is the motor RT stage which represents the process associated with the musculature itself (refer to Figure 1).

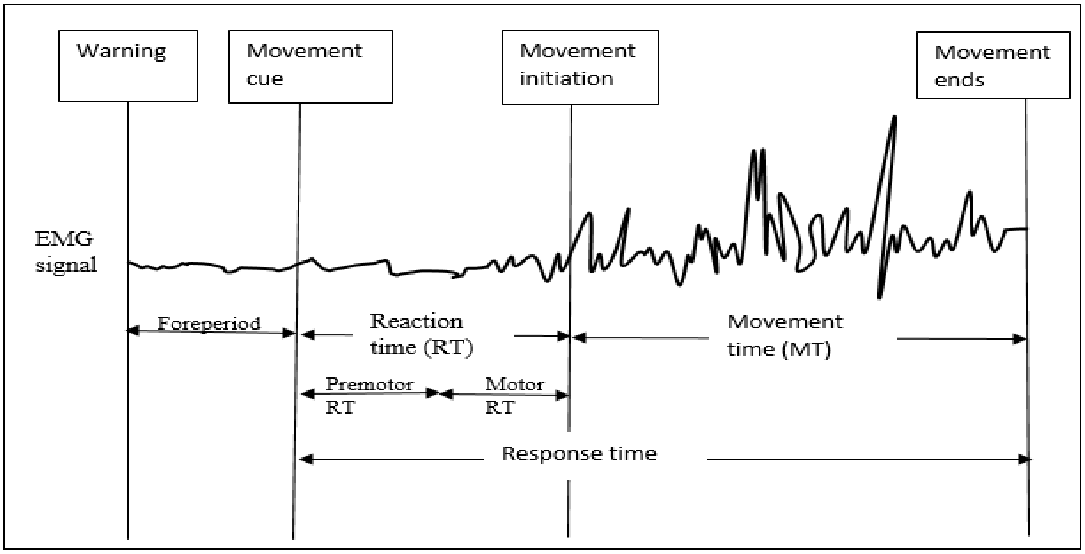

Figure 1: Events involved in the reaction time paradigm (Adapted from Schmidt and Lee, 2010).

Movement time is defined as the interval from the initiation of a response (the end of RT) to the end of the moment (Schmidt and Lee, 2010) (Figure 1). However, like reaction time, there are several events that occur during the movement time phase to a target. Researchers have proposed that it is composed of an initial primary movement that is followed by a corrective phase (Elliott, Hansen, Grierson, lyons, Bennett & Hayes., 2010; Keele & Posner, 1968; Woodworth, 1899). Woodworth's (1899) seminal work defined two distinct phases of movement control: the initial impulse distance covering phase which brings the limb to the area of the target, and the homing or corrective phase where proprioceptive and visual feedback are used to home in on the target (Elliott et al., 2010) (refer to Figure 2). According to Woodworth, movement planning and online control play significant roles in the precision required for manual aiming. Woodworth proposed that the impulse phase was ballistic in nature. This idea inspired a series of different models. Most recently, the more complex multiple processes model involved in goal-directed aiming was proposed by Elliott et al. (2010). This model maintains Woodworth's two components of movement and includes discussion regarding endpoint variability. In addition, Elliott et al. (2010) proposed that the distance-covering phase of goal-directed movement was not entirely ballistic but reflects how performers try to find a balance between how fast their movement can be while still hitting the target. This is in contrast to Woodworth's description of the initial phase being ballistic. The latter segment of an aiming movement relies on sensory feedback from vision and proprioception (limb position in space with respect to the target location) in order to make necessary adjustments or corrections that brings the limb to the desired target location. According to Elliott and Khan (2010), analysis of movement velocity, acceleration and termination or discontinuities provide important insight into movement planning and limb control. Therefore the latency preceding movement initiation (RT) and the initial segment of the trajectory (peak acceleration and peak velocity) reflect movement planning, while the latter segment of the trajectory reflects online control and correction (Figure 2).

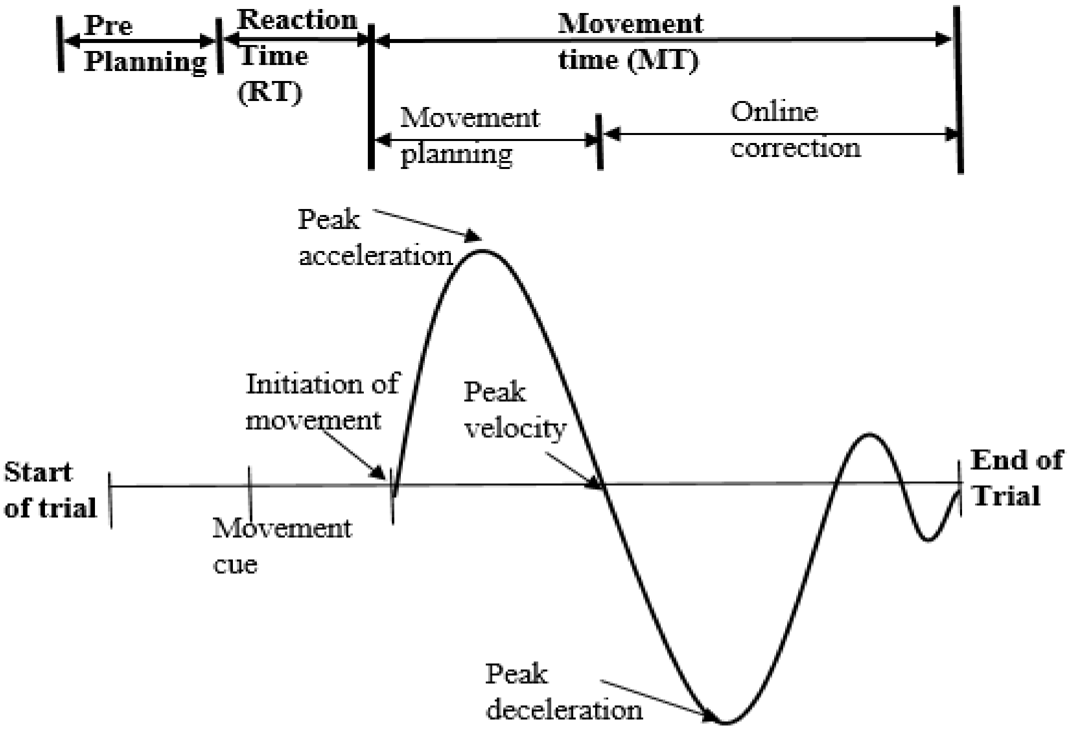

Figure 2 : Movements Event (Adapted from Elliott et al. 2010)

Researchers have also investigated the effect of available information before movement onset on both RT and the initial segment of movement trajectories. They have varied if participants are aware of the availability or unavailability of certain cues or feedback. For example, Hansen, Glazebrook, Greg Anson, Weeks, & Elliott (2006) examined the strategy that participants used when preparing movements when vision was or was not available. The results from this study showed that when vision was available to participants, movement trajectories showed asymmetric velocity profiles whereby more time was spent after peak velocity (online control) than before peak velocity (movement planning). Participants also had shorter RTs and time to reach peak velocity. However, when participants were uncertain about the availability of vision, they made use of the worst case scenario plan of not having vision. The kinematic results in this scenario resembled when vision was not provided whereby the velocity profile was more symmetric with participants spending more time planning their movement, which resulted in a longer RT. This increased time spent preparing the movement allowed participants to strengthen the memory representation of the target so as to reduce endpoint errors in the occasion that vision was not available for online corrections (Hansen et al., 2006). Similar findings was reported by Peters & Glazebrook (2020), whereby auditory stimuli heard before and during a movement resulted in faster RTs and fewer endpoint errors, leading to better accuracy even when visual feedback was not available to participants.

To summerize, studies have shown that strategies employed in how we plan and execute our movements are affected by the information available. In particular, trajectory analysis can provide useful insight into the strategies being employed to optimize movements under varying conditions (Song & Nakayama, 2008). For the sake of the current thesis, participants will be aiming to multiple targets presented on a screen. Hence, it is essential to understand what strategies used in moving to multiple targets.

Multiple target processing

As humans, we are continually faced with numerous opportunities or decisions that require a response. Typically, our environment tends to be visually clustered with various competing targets for response and rarely are we presented with a single object or target. For example, reaching to a jar of salt on a counter filled with similar jars with different spices. How are we able to reach accurately to the jar labelled salt and not the similar jar labelled pepper or garlic? A theory proposed by Cisek (2007) states that multiple potential targets for action are partially encoded in parallel and compete for execution such that neuronal activities creates overlapping hills until inhibition of neurons for those activities that are not required falls below baseline (Cisek, 2007; Cisek & Kalaska, 2005). Evidence of parallel target encoding emerged from the neural recordings in macaque monkeys which showed that the premotor cortex (dorsal premotor) and midbrain (superior colliculus) were responsible for encoding reaching action to multiple potential targets (Cisek & Kalaska, 2005). Further studies have shown that these areas of the brain are involved in the ability to consider probabilities and represent quantity, which are both necessary when deciding between alternatives. Kinematic studies of eye and hand movements made towards visual targets in the midst of distractors that share similar features to the target have been shown to influence deviations in gaze (McSorley, Haggard, & Walker, 2006; Walker, McSorley, & Haggard, 2006) and reach trajectories (Oladokun et al. 2017; Matthew Ray, Weeks, & Welsh, 2014; Tipper, Lortie, & Baylis, 1992; Welsh & Elliott, 2004; Welsh, Elliott, & Weeks, 1999). When the proximity of the distractor and target is close, a phenomenon called spatial averaging is observed whereby participants move between the target and distractors. It is thought that spatial averaging occurs because of the overlapping of neural activities within the part of the brain that controls the body part being moved. For instance, neural activity occurring in the superior colliculus during eye movement and activities within the motor cortex during arm movement (McPeek, Han, & Keller, 2003; Tipper, Howard, & Jackson, 1997). Spatial averaging happens because the visuomotor system initially processes both targets and distractors as potential targets (McPeek & Keller, 2004). Therefore, the process of selecting a particular object in the midst of distractors reflects the strength of the vector sum of neuronal activities encoding a response to the selected object. The presence of distracters influences the trajectory of a reach to a target suggesting that multiple target- and distracter-related directional signals coexist in neural populations specifying reach direction (Tipper et al., 1998). In Tipper et al.'s (1997) experiment, participants were required to reach and grasp a target in the presence of a target distractor, and their movement trajectories recorded. Results showed that unlike movements to the single targets, movement time was longer in the distractor conditions. Also, trajectory analysis revealed deviations toward a non-target (distractor) which provides supporting evidence of spatial averaging, which supports the neuronal activity explanation.

The availability of sensory information at different stages of motor planning can affect how we move to the target. More specifically, studies have shown that having a cue before target presentation positively influences the time it takes to initiate the movement. For instance, studies show that the availability of task-related information during rapid reaching can influence movement in flight even when the information was not consciously perceived. Results from Schmidt (2002) showed that when pointing to one of two colour targets, having congruent or incongruent colour primes affected the movement trajectories. Similarly, Oladokun et al. 2017 found that congruent, exogenous auditory cues have the potential to enhance reach performance during multi-target tasks through earlier trajectory deviations toward the target. These results provide evidence that there is a continuous updating of target information in the brain even after movement initiation. While endogenous visual cues benefit performance, the role of endogenous auditory cues in multi-target aiming is poorly understood. Endogenous auditory cues are relevant in real-world scenarios whereby auditory cueing or sounds serve as warning mechanisms. For example, while driving a car, there are many potential visual targets that we can respond to. If we hear a warning sound telling us about potential dangers, can that signal help us select the correct response? How do we respond appropriately in order to ensure our safety and the safety of others?

The experimental procedure in the current thesis will build on the procedure of Chapman et al. (2010) by cueing one of the four competing targets after participants initiate their movement. According to Wispinski et al. (2021), this type of task is also known as a “Go-before-you-know-task”. The approach used will allow a detailed assessment of the tight coupling of attention and multisensory integration of auditory cueing and action to multiple probable targets.

Purpose and hypothesis

This experiment sought to determine the effects of congruency (validity) of endogenous auditory stimuli on reaching performance to multiple targets by evaluating performance measures (reaction and movement time) and kinematic variables such as movement trajectory. It seeks to explore the coupling of attention and action by measuring the influence endogenous auditory cues have on the stages of movement planning and execution. Thus, this study seeks to answer the question of how participants use the available information in the form of auditory cues presented immediately after movement initiation to update the movement plan and execute their movement to a previously undetermined target location.

Hypothesis

1. There will be no statistical main effect of condition and target location on reaction time.
2. There will be statistically significant effect of condition on Movement time with valid condition having the shortest Movement time.
3. There will be statistically significant effect of condition on percentage time of movement to peak velocity (%ttPV) with the valid condition having shorter %ttPV in other to allow more time for online correction of reach trajectory to the presented target location.
4. There will be statistical significance of condition and target location on Constant error and variable error, with the valid condition having the smallest constant and variable error values.
5. There will be significant trajectory deviation at about 60% of movement time.
6. Trajectory analysis will show spatial averaging strategy being used by participants.

Approach

Develop an experimental paradigm to:

i. Replicate findings from previous experiments using a multi-target paradigm.

ii. Evaluate the effects of cue-target congruency of endogenous auditory cues on movement planning and execution.

iii. Reanalyze current data by varying the kinematic onset and offset threshold from 30mm/s to 15mm/s.

Chapter Three

Methods

Participants

Twelve right-handed neurotypical participants (mean age 22.2 years; 7 females, 5 males) were recruited from the University of Manitoba community. Recruitment was performed using fliers on various visible poster boards on campus. The opportunity to participate in this research study was also presented to students in class by a research assistant. Ethical approval (Appendix A) was obtained from the Educational/Nursing Research Ethics Board (ENREB) of the University of Manitoba. All participants consented by signing an informed consent form (Appendix B) after reading all the necessary information on the consent form. A self-reported questionnaire (Appendix C) was then completed by participants, indicating they were right-handed, free from any neurological disorder, orthopaedic conditions, had a normal or corrected-to-normal vision and normal hearing. A sensitivity power analysis on our sample size of 12 participants was performed using G-power 3.1.9.3. The parameters imputed were alpha at 0.05, Power value was set at 0.95, the number of groups and number of measurements was set at 1and 3 respectively, the correlation among repeated measures was set at a conservative 0. This resulted in an effect size f of 0.50 which is a large effect.

Instruments

Participants performed the target aiming task on a Dell Touch Screen Computer Monitor (Dell ST2220T; 37.99 x 52.81 x 5.84cm, displaying 1920 x 108 pixels). The monitor was placed on a table 75cm high and was tilted at approximately 32^0 angle. The home button was made of a short lever snap action switch and positioned at the midpoint (19.5cm) from the edge of the table (Figure 4). Two black Logitech speakers were placed behind the monitor to present the auditory stimuli. The monitor was used to display the experimental instructions and targets for the participants. The potential targets included four square targets (1 x 1cm) in fixed locations at 38cm from the home button (Figure 3). Participants were required to sit on an adjustable chair which could be adjusted to vary the distance from the edge of the table to a desired comfort level. The distance to the targets was consistently 38cm from the home button to the middle if the monitor screen where the target is presented (Figure 4).

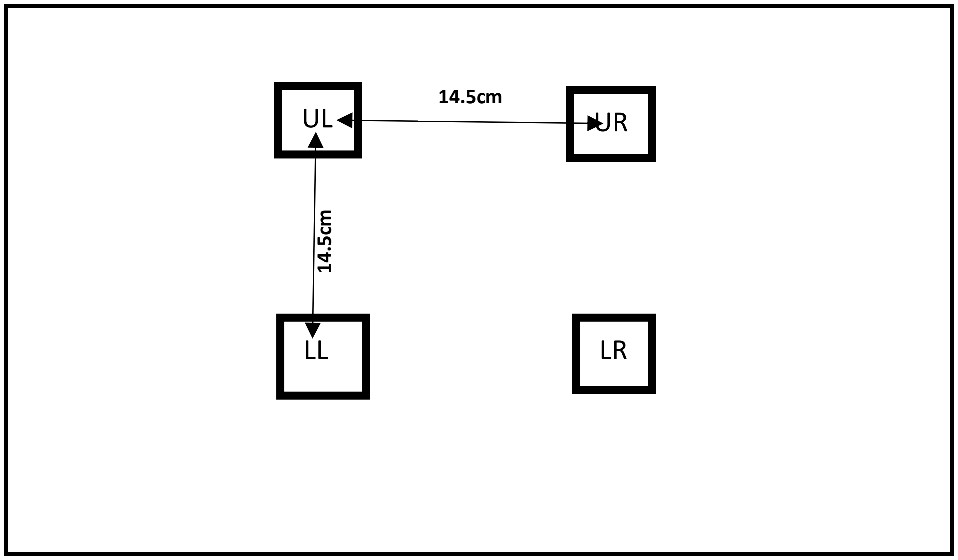

Figure 3: Target Locations on the screen. UL=upper left, LL= lower left, UR= upper right and LR =lower right target location.

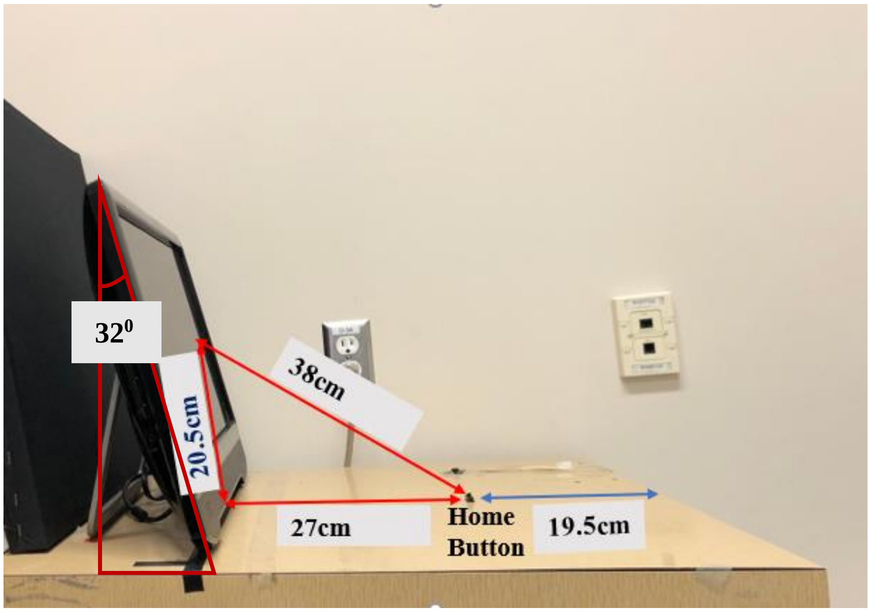

Figure 4: Experimental setup with dimensions in view

An Optotrak 3D Motion Capture System (3D Investigator, Northern Digital Inc., Waterloo, ON) was used to track infrared light-emitting diodes (Figure 5). The infrared markers (IREDs) were attached to the tip of the right index finger using Blenderm (3M) medical tape. The wires of the IRED were further secured on the participants' forearms with the medical tape to prevent excessive IRED movement and movement impediment. The 3D (3 Dimensional) positions of the IRED i.e., x-(medio-lateral), y- (anterior-posterior) and z- (vertical) axis, was sampled at 500Hz for 2 sec by an Optotrak Certus 3D motion capture system (Northern Digital, Ontario Canada). Custom experimental software designed using E-Prime Software (version 2.0.8.74, Psychology Software Tools Inc, Pennsylvania, USA.) controlled the synchronized initiation of the visual display and auditory cue presentation. The program also triggered the motion analysis system to record the location of the IREDs for offline analysis.

Figure 5: Optotrak Certus 3D Motion Analysis System (Northern Digital, Inc.)

Procedure

In this experiment, there were three conditions: No-sound/uncued, Valid/congruent and Invalid/incongruent conditions. The uncued condition was a no-sound condition whereby the participant completed the movement without auditory information. The valid condition consisted of a high tone (1250Hz) paired with movement to the upper targets and a low tone (250Hz) paired with movements to the lower targets. In contrast, the Invalid condition consisted of a high tone (1250Hz) towards lower targets and a low tone (250Hz) towards upper targets. Participants completed the experiment in a single session that lasted approximately 60 minutes in duration. Instructions regarding the experiment's procedure were then explained to the participants, and they were aware that the auditory cue could predict the target location only 50/50.

Each condition consisted of 80 trials that were randomly presented to the participant, and each trial began with the participant placing their index finger on the home button, thereby depressing it. As illustrated in Figure 6, following the presentation of a “ready” sign on the screen (controlled by the experimenter), a “fixation cross” was presented that lasted for 1000ms. After which, a variable fore period lasting between 300ms to 850ms was presented. Participants initiated their movement (within 100-325ms) towards the screen with their index finger releasing the home button in response to a visual ‘Go’ signal which was the presentation of green outlined targets. Upon movement initiation the auditory tone (0Hz, 250Hz, or 1250Hz) was emitted. Simultaneously, one of four equiprobable visual targets was indicated as the target for that trial by being filled in solid black. Feedback was given to participants if they were “correct” “too fast” or “too slow” in initiating their movement and if their movement was initiated within the set temporal measure. For example, if a participant responded outside the set temporal measure and too slow or too fast on a trial, they would get a script in red font saying “Too Slow 0.400 seconds response time or Too Fast, 0.080 seconds response time”. However, if they responded within the set temporal measure and were correct, they would get a script in blue font saying “Correct, 0.300 seconds response time”. Trials that were either too fast or too slow were excluded from subsequent analysis. Each session consisted of 24 familiarization trials and 240 test trials (80 valid trials, 80 invalid trials and 80 uncued trials) presented randomly (Table 1).

Table 2: Table showing the numbers of trials in each condition and target location.

	Upper Targets	Lower Targets
No-sound Condition	40 Trials	40 Trials
Valid Condition	40 Trials	40 Trials
Invalid Condition	40 Trials	40 Trials

Before each session, participants were instructed to reach and touch the indicated target as quickly and accurately as possible. Three-minute mandatory breaks were given to each participant strategically presented after completing 80 trials. Participants were also encouraged to take breaks when they felt like it was needed. At the end of the testing session, target files were collected to quantify the relative location of the IREDs at each target location on the monitor. This was used to calculate the constant and variable error for each participant. During the experiment, field notes were recorded by the experimenter to confirm E-prime trial numbers and Optotrak files and to document observed errors that may have occurred during the testing session.

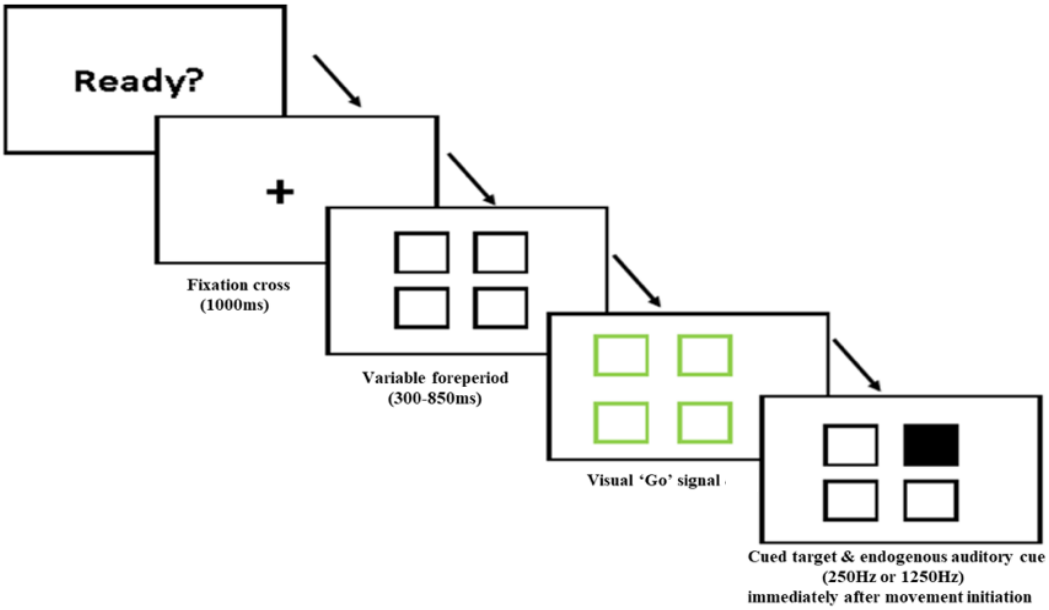

Figure 6: Schematic program of the experiment.

Data Processing and Analysis

First, all blank files (files that occurred when E-prime software un expectedly automatically triggered the Optotrak during the protocol) and trials that the experimenter noted on the field as trials with potential error (for example trials where participants were distracted, recording of the 24 practice trials for one participant and the sudden onset of external distractors e.g. construction vibrations and loud noise) were manually removed from the data set. A total of 192 trials (5.8% of the total trials) were manually excluded. The remaining displacement data collected via the Optotrak system was then processed using a custom program on MatLab which analysis reaching kinematics (MatLab, The Mathworks Inc. 2016b version). In the MatLab program, the organized raw data was inputted and then preprocessed by filling in gaps and smoothing with a third order Butterworth lowpass at 15Hz before specifying kinematics thresholds. In the initial analysis, the movement onset was defined as the first frame that the marker on the limb reached a velocity of 30mm/s and maintained that velocity for 30ms. Movement offset was defined as the first frame that the marker on the limb fell below a velocity of 30mm/s and maintained that velocity for 30ms (refer to Figure 7 for a visual representation). After inputting these thresholds, 321trials (11% of total trials) were excluded by MatLab software because the reach marker was already moving at trial onset.

However, for the re-analysis of this data, the movement onset was defined as the first frame that the marker on the limb reached a velocity of 15mm/s and maintained that velocity for 15ms. Movement offset was defined as the first frame that the marker on the limb fell below a velocity of 15mm/s and maintained that velocity for 15ms (refer to Figure 7 for a visual representation). After inputting these thresholds, 1308 trials (45% of total trials) were excluded by MatLab software because the reach marker was already moving at trial onset. The z-axis was defined as the primary axis, while the x-axis is the secondary axis. The resultant 3D velocity vector was used for trajectory analysis.

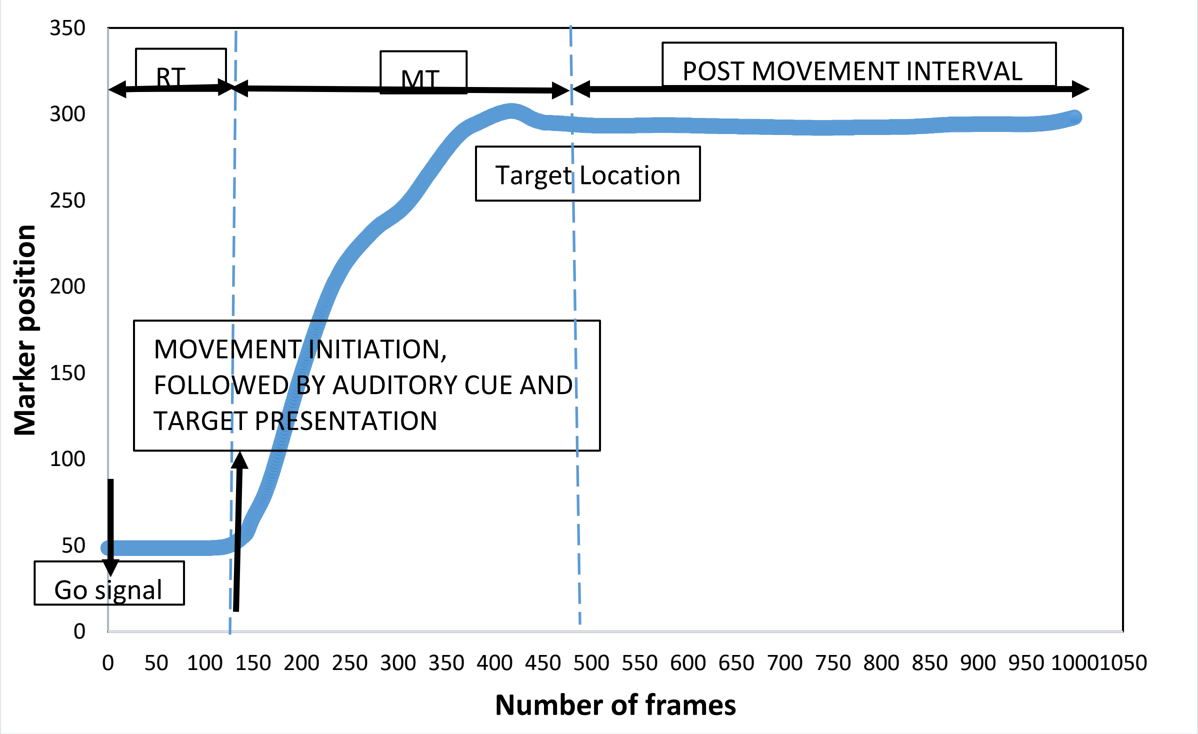

Figure 7: Sample data of one trial with movement events adapted from Elliott et al. (2010).

The primary dependent variables were;

- Reaction time (RT) in milliseconds - Time from when the go signal was presented to the time the index finger leaves the home button.

- Movement time (MT) in milliseconds - Time it takes to leave the home button and touch the target presented on the screen.
- Trajectory deviation at 5 positions during MT (20%, 40%, 60%, 80% and 100% of MT).

The secondary dependent measures were;

- Percentage time to peak velocity (% ttPV),
- Constant error (CE) in the horizontal (x) and vertical (z) axes, which measures the deviation from the actual target location.
- Variable error (VE) in the horizontal (x) and vertical (z) axes, which measures the consistency of the final location of the aiming trials.

In the initial analysis, movement initiation was defined as any movement that exceeded 30mm/s for more than 30ms and in the follow-up analysis, it was defined as any movement that exceeded 15mm/s for more than 15ms. Similarly, movement termination was defined as the first sample in which the velocity fell below 30mm/s and remained below the threshold for at least 15 samples after movement initiation in the initial analysis and 15mm/s in the follow-up analysis. RT was calculated by multiplying the sampling rate by the number of samples recorded from the "Go" signal (cue to initiate movement) to the defined movement initiation. In order to calculate MT, the sampling rate was multiplied by the number of frames recorded between the defined movement initiation and movement end. The constant error was calculated by computing the average of the location of the IRED at movement end on both the z and x-axis, while variable error was calculated by computing the SD of the location of the IRED at movement end. A differential of the displacement data from movement initiation was used to compute time to peak limb velocity (ttPV) in the primary axis (z) while the percentage time to peak limb velocity (%ttPV), which shows the percentage of movement when ttPV occurred was a function of ttPV divided by the MT.

Prior to Statistical analysis, outlier trials were removed by determining the inclusion upper and lower limits which was calculated for each participant as 2.5 standard deviations above and below the mean for the reaction time and movement time. Therefore, trials that fell outside of these limits were excluded from analysis. Statistical analysis was performed using a free and open statistical platform, Jamovi 2.0 software (The Jamovi Project, 2021). Target location were also collapsed horizontally into upper and lower targets for easier data interpretation purposes. i.e. left and right targets data was merged.

In the initial analysis, one participant was excluded from the data because the majority (over 90%) of the data collected were excluded due to the criteria's mentioned earlier. While in the follow-up analysis, two participants were excluded due to the same reason of losing over 90 % of the data. After the outliers were removed, repeated measures ANOVAs were used to analyze the dependent variables. A 2-way repeated measure (3 condition by 2 target) ANOVA was used for performance variables while a 3 condition by 2 targets by 5 MT trajectory location was used for trajectory analyses. Significance level was set at $p < .05$, and significant interactions involving more than two means were further investigated using Tukey's HSD (post hoc analysis), $p < .05$.

In addition to analyzing kinematic data from Optotrak, reaction time data from the microswitch measured through Eprime software which recorded the release of the microswitch that served as the start position during this experimental task was analyzed, because we wanted to validate the reaction time analysis output from the Kinematic data recorded through Optotrak. Before re-analyzing the data recorded from the microswitch, the trials removed from the Optotrak trajectory data analysis were removed to match the kinematic data analyzed using 30mm/s velocity onset. This procedure was repeated with the kinematic data analyzed with the 15mm/s velocity onset threshold data. The microswitch RT data recording was then statistically analyzed using a 2-way repeated measure (3 condition by 2 target) ANOVA.

Chapter Four

Results

The order of result presentation is as follows: The initial results using 30mm/s velocity threshold for movement onset and offset are presented first. Next, the results from the analysis using the 15mm/s velocity threshold for movement onset and offset. Finally, the results of the analysis of the RT of the microswitch embedded in the table recorded by the Eprime software will be presented. Note that for the microswitch RT data analyzed, only the trials included in the 30mm/s and 15mm/s velocity threshold data were used to validate the analysis; hence the analyzed trials were matched to those analyzed in the movement kinematic analysis. Finally, Table 10 presents a summary of the results from the different data analyses.

Results from 30mm/s onset and offset Kinematic threshold analysis

Temporal measures

Reaction time. The analysis of reaction time (RT) showed a significant main effect of condition [F(2, 20)= 3.519, p=0.049] such that the valid condition (M=251ms, S.D= 51ms) was significantly faster than the no-sound condition (M= 259ms, S.D= 60ms) (Figure 8) as revealed by a post hoc analysis. There was no significant main effect of target location [F(1,10)= 0.204, p=0.661] and no significant interaction between target and condition [F(2,20)= 0.04, p=0.996].

For reaction time variability, There was no significant effect of condition [F(2, 20)= 1.731, p=0.203], target location [F(1,10)= 0.146, p=0.711] and no significant interaction between condition and target location [F(2,20)= 1.047, p=0.369].

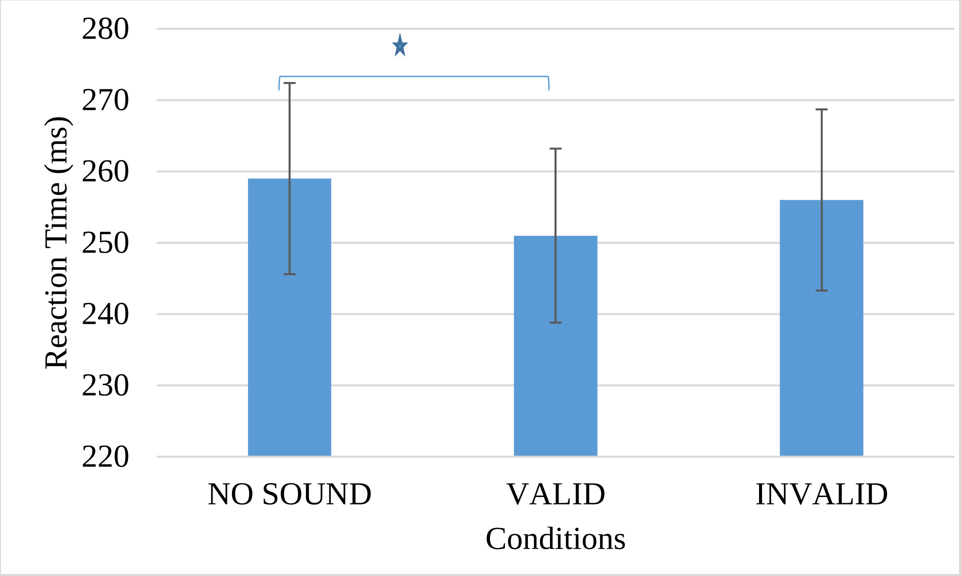

Figure 8: Mean Reaction time (ms) as a function of condition. Error bars show standard error measures. * indicates significant difference (a < 0.05).

Movement Time (MT). A significant main effect of target location was observed [F (1,10) =8.863, p=0.014] such that the lower targets had a shorter mean movement time (668ms) when compared to the upper targets (683ms) (Figure 9). The result showed no significant main effect for condition [F (2, 20) =1.527 p=0.241] (Table 2) and no significant interaction of target and condition [F (2,20) = 0.742, p=0.489].

For movement time variability, There was no significant effect of condition [F(2, 20)= 0.944, p= 0.406], target location [F(1,10)= 2.237, p=0.166] and no significant interaction between condition and target location [F(2,20)= 01.518, p=0.243].

Table 3: Mean movement time (ms) in each condition.

			95% Confidence Interval	
Condition	**Mean**	**SE**	**Lower**	**Upper**
No-sound	672	18.5	630	713
Valid	683	18.9	641	725
Invalid	672	19.7	628	716

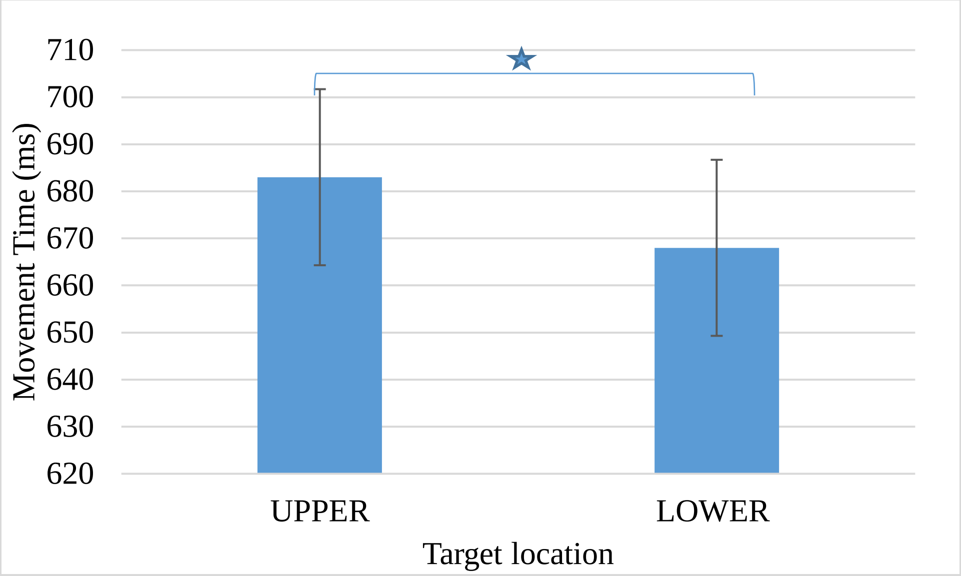

Figure 9: Mean movement time (ms) as a function of target location. Error bars show standard error measures. * indicates significant difference (a < 0.05)

Percentage Time to peak velocity (%ttPV). Significant main effect of target location was observed for the %ttPV [F(1,10)= 24.747, p<0.001] with participants spending more time to peak velocity to the upper targets (43.5%) than the lower targets (29.7%) regardless of condition (Figure 10). Results from the analysis showed no significant main effect for condition [F(2 20)=1.566 p=0.233] was observed, neither was there a significant interaction between target and condition [F(2,20)=0.522, p=0.601)].

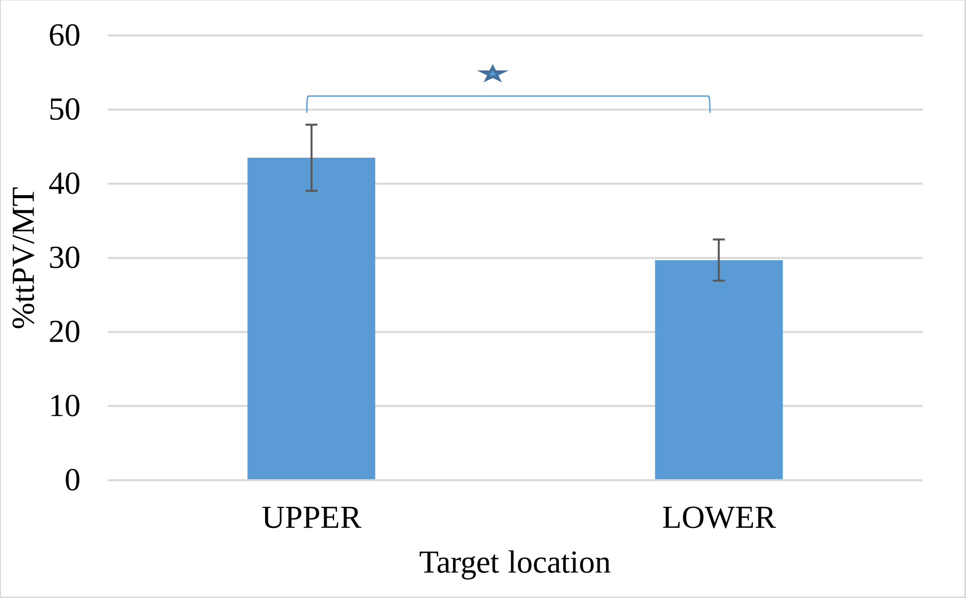

Figure 10: Percentage of movement time to peak velocity as a function of target location. Error bars show standard error measures. * indicates significant difference (a < 0.05).

Endpoint performance measure

Constant error (CE) in millimeter: On the z-axis, no significant main effect for condition [F (2,20) = 0.157 p=0.856] or target location [F (1.10) = 0.089 p=0.771] was observed. There was also no significant interaction of target and condition [F (2, 20) = 2.939, p=0.076]. The mean constant error on the x-axis for the no-sound, valid and invalid conditions is shown in Table 3

Table 4: Mean values for constant error on the z-axis.

			95% Confidence Interval	
Conditions	**Mean**	**SE**	**Lower**	**Upper**
No-sound	-1.33	0.934	-3.41	0.75
Valid	-1.05	0.885	-3.02	0.925
Invalid	-1.43	1.177	-4.05	1.195

Analysis of constant error on the x-axis was not significantly different in the effect of condition [F (2,20) = 1.202 p=0.321], target [F (1,10) = 3.592 p=0.087] and interaction of target location and condition [F (2,20) = 0.203, p=0.818]. The mean constant error score on the x-axis for the no-sound, valid and invalid conditions are shown in Table 4

Table 5: Mean values for constant error on the x-axis.

Condition	Mean	SE	95% Confidence Interval	
			Lower	Upper
No-sound	3.23	0.506	2.11	4.36
Valid	3.04	0.413	2.12	3.96
Invalid	3.83	0.788	2.07	5.59

Variable error (VE) in millimeter: Analysis of variable error on the z-axis was not significantly different in the effect of condition [F (2,20) = 1.67 p=0.214], and target [F (1,10) = 1.29 p=0.282]. However, there was a significant interaction between target location and condition [F (2,20) = 4.18, p=0.031]. Post hoc analysis on the interaction did not reveal significance between the target locations at the three conditions. The mean variable error score on the z-axis for the no-sound, valid and invalid conditions at both upper and lower target location is shown in Table 5.

Table 5: Mean values for variable error on the z-axis.

CONDITIONS	TARGET LOCATION	Mean	SE	95% Confidence Interval	
				Lower	Upper
No-sound	Up	10.32	3.87	1.7	18.9
	Down	9.74	1.84	5.64	13.8
Valid	Up	10.56	3.91	1.85	19.3
	Down	10.26	1.86	6.12	14.4
Invalid	Up	21.43	7.62	4.46	38.4
	Down	10.21	2.52	4.6	15.8

Analysis of variable error on the x-axis revealed no significant difference in the effect of condition [F (2,20) = 1.145 p=0.338] and target location [F (1,10) = 0.234, p=0.639]. The interaction between target location and condition was also not significantly different in on the x-axis [F (2,20) = 1.096 p=0.354]. The mean variable error score on the x-axis for the no-sound, valid and invalid conditions are shown in Table 6.

Table 6: Mean values for variable error on the x-axis.

			95% Confidence Interval	
Conditions	**Mean**	**SE**	**Lower**	**Upper**
No-sound	5.73	0.674	4.23	7.23
Valid	6.15	0.726	4.53	7.77
Invalid	7.54	1.357	4.52	10.56

Movement trajectory analysis

Movement Trajectory. The analysis of movement trajectory as a function of the percentage of MT, showed a significant main effect of target location [F (1,10) =1221.923, p<0.001] and movement trajectory [F (4,40) =147.025, p<0.001]. There was also a significant interaction between target location and movement trajectory [F (4,40) =709.46, p<0.001]. However, there was no significant main effect of condition [F (2, 20) =0.705, p=0.506], no significant interaction between condition and trajectory [F (8,80) =0.354, p=0.941] and no significant interaction between condition and target location [F (2,20) =0.882, p=0.429]. There was no significant interaction between condition, target location, and movement percentage [F (8,80) =1.173, p=0.326]. Post hoc analysis revealed significant deviations between the upper and lower targets began at 60% of movement and ended at movement completion (Figure 11).

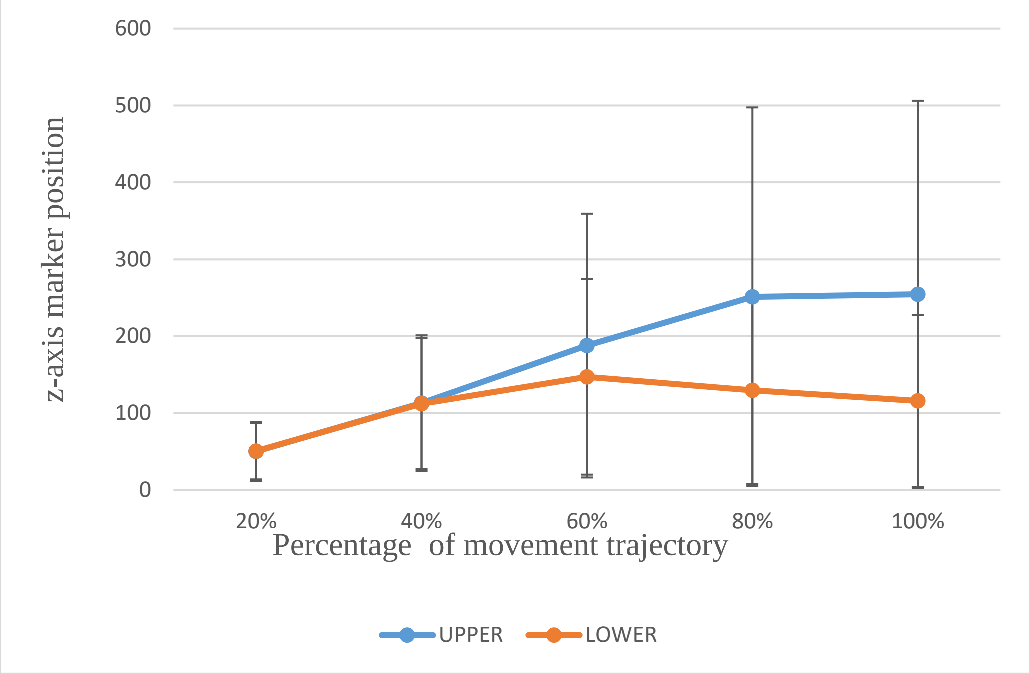

Figure 11: Interaction between mean movement trajectory and percentage movement time point. Error bars show standard error measures. * indicates significant difference (a < 0.05)

For movement trajectory variability in the z-axis, there was a significant main effect of movement trajectory [F (4,40) = 25.82, p <0.001]. There was also a significant interaction of target location and Movement trajectory [F (4,40) =4.867, p=0.003]. There was no significant main effect of condition [F (2,20) = 3.0, p =0.075], target location [F (1,10) = 2, p=0.19] and no significant interaction between condition and Movement trajectory [F (8,80) =0.84, p=0.571], condition and target location [F (2,20) =1.493, p=0.249]. There was also no significant interaction of condition, target location, and Movement trajectory [F (8,80) =1.925, p=0.067]. Post hoc analysis showed significant differences in the standard deviation between the upper and lower targets at 40% of the Movement trajectory (Figure 12).

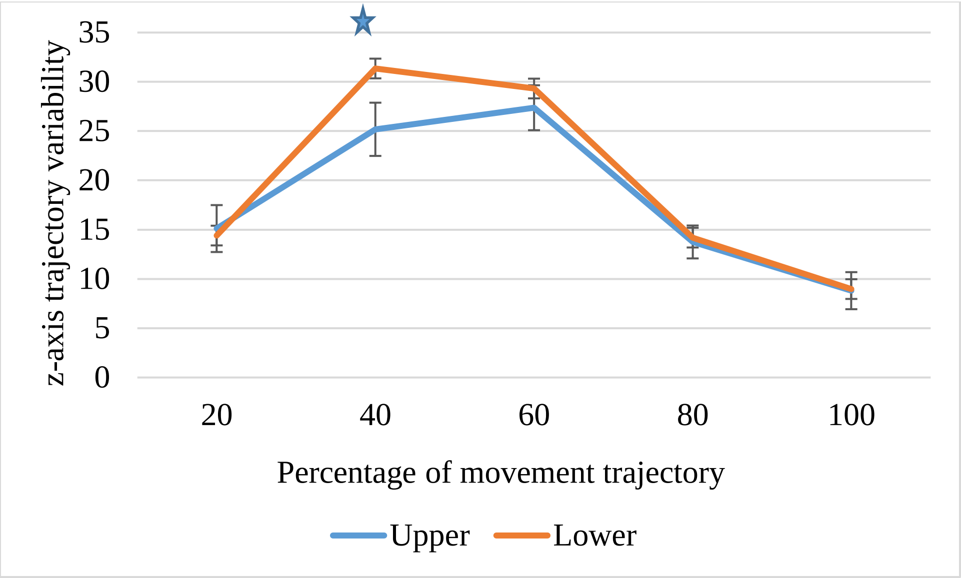

Figure 12 : Standard deviation of Movement trajectory as a function of percentage movement time. Error bars show standard error measures. * indicates significant difference (a < 0.05).

Results from 15mm/s onset and offset Kinematic threshold analysis

Temporal measures

Reaction time result from kinematic data. The analysis of reaction time (RT) showed no significant main effect of condition [F (2, 18) = 0.228, p=0.798] and target location [F(1,9= 0.929, p=0.36]. There was also no significant interaction between target and condition [F(2, 18)= 0.377, p=0.691]. The mean data for each condition is represented in Figure 13.

For reaction time variability, There was no significant effect of condition [F(2, 18)= 0.27, p=0.763], target location [F(1,9)= 0.02, p=0.905] and no significant interaction between condition and target location [F(2,18)= 1.76, p=0.2].

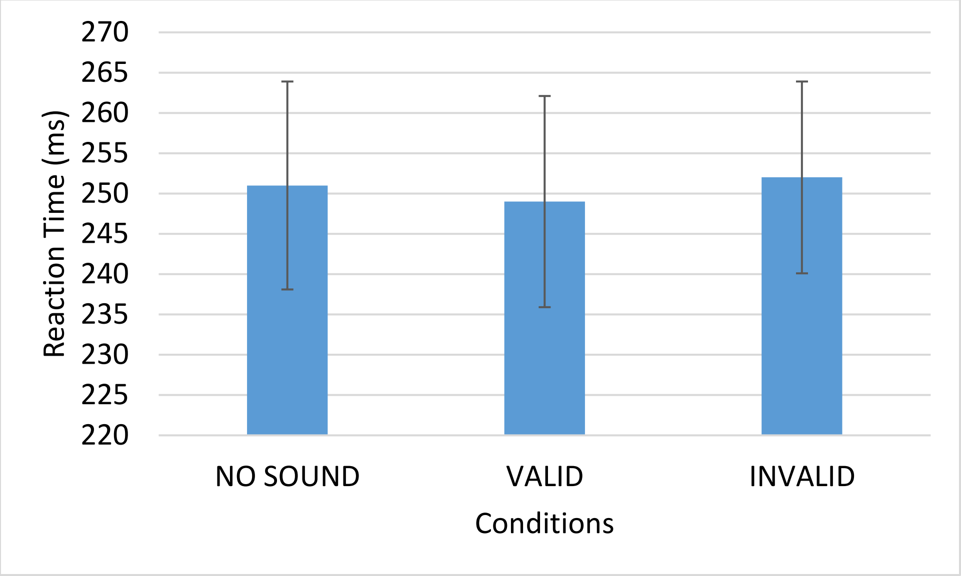

Figure 13: Reaction time at 15mm/s threshold. Error bars show standard error measures.

Movement Time (MT). A significant main effect of condition was observed [F (2, 18) = 5.222, p = 0.016] such that the valid condition (792ms) is significantly longer MT than the no-sound condition (772ms). The result showed no significant main effect of target location [F (1, 9) = 2.423 p= 0.154] and no significant interaction of target location and condition [F (2,18) = 0.640, p = 0.539]. Post hoc analysis revealed that MT was significantly longer in the valid condition than in the no-sound condition (792ms and 772ms, respectively) regardless of target location (Figure 14).

For movement time variability, There was a significant main effect of target location [F(1,9)= 9.13, p=0.035] with the upper targets having smaller variability (72.3ms) than the lower targets (89ms). However, there was no significant effect of condition [F(2, 18)= 0.27, p=0.767] and no significant interaction between condition and target location [F(2,18)= 0.19, p=0.829].

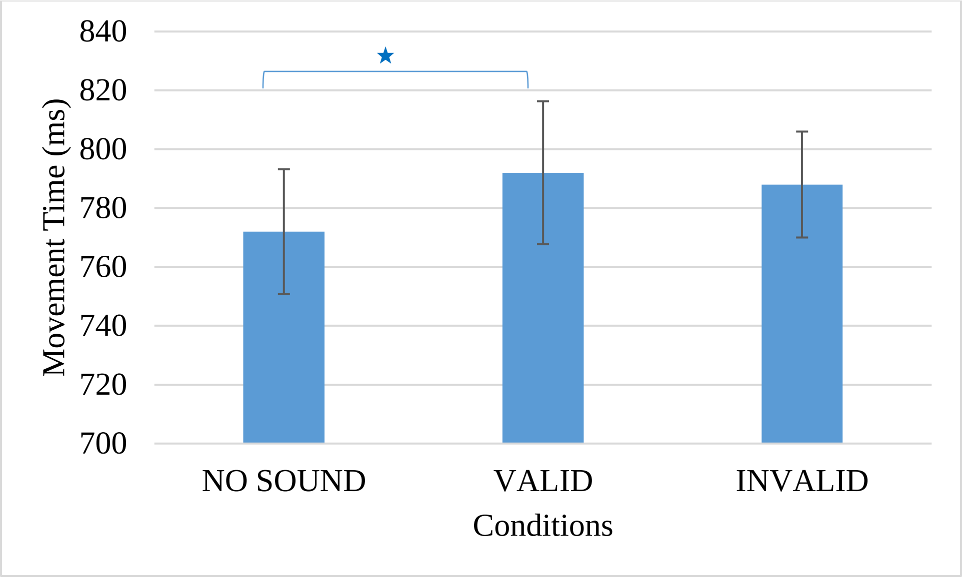

Figure 14: Movement time at 15mm/s threshold. Error bars show standard error measures. * indicates significant difference (a < 0.05).

Percentage time to peak velocity (%ttPV). Significant main effect of target location was observed for the % ttPV [F(1,9)= 22.597, p = 0.001] with participants spending more time to peak velocity to the upper targets than the lower targets regardless of condition (41.5% of MT and 31.4% of MT respectively) (Figure 15). Results from the analysis showed no significant main effect for condition [F(2,18)=1.307 p=0.295]; neither was there a significant interaction between target and condition [F(2, 18)=0.178, p=0.838].

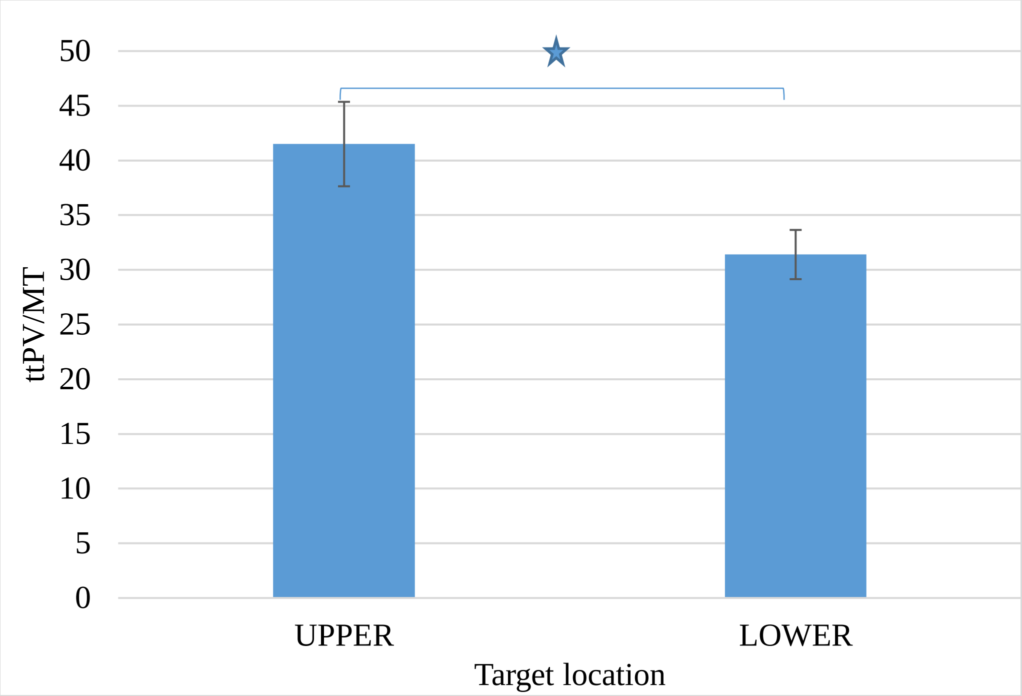

Figure 15: Percentage time to peak velocity by target location. Error bars show standard error measures. * indicates significant difference (a < 0.05).

Endpoint performance measure

Constant error (CE) in millimeter: On the z-axis, there was no significant main effect for condition [F (2, 18) = 2.183, p=0.142], target location [F (1,9) = 2.061 p= 0.185] and no significant interaction of target location and condition [F (2,18) = 0.262, p = 0.773] observed. The mean constant error on the z-axis for each condition is represented in Table 7.

Table 7: Mean values for constant error on the z-axis.

			95% Confidence Interval	
CONDITION	**Mean (mm)**	**SE**	**Lower**	**Upper**
No-sound	-2.115	0.734	-3.78	-0.455
Valid	-1.348	1.108	-3.86	1.159
Invalid	-0.464	0.868	-2.43	1.5

Analysis of constant error on the x-axis was not significantly different for the effect of condition [F (2, 18) = 1.993, p= 0.165] and target location [F (1,9) = 1.417 p= 0.264]. There was also no significant interaction between target location and condition [F (2, 18) = 0.552, p= 0.585]. The mean constant error on the x-axis for each condition is represented in Table 8.

Table 8: Mean values for constant error on the x-axis.

			95% Confidence Interval	
CONDITIONS	**Mean (mm)**	**SE**	**Lower**	**Upper**
No-sound	2.24	0.643	0.7888	3.7
Valid	1.36	0.631	-0.0634	2.79
Invalid	1.31	0.528	0.1138	2.5

Variable error (CE) in millimeter: Analysis of variable error on the z-axis showed significant main effect of target location [F (1,9) = 15.275 p=0.004] with participants having larger variability error values to the lower target that the upper targets (Figure 16). However, there was no significant main effect of condition [F (2, 18) = 0.218, p = 0.806]. There was also no significant interaction between target location and condition [F (2, 18) = 1.411, p = 0.27].

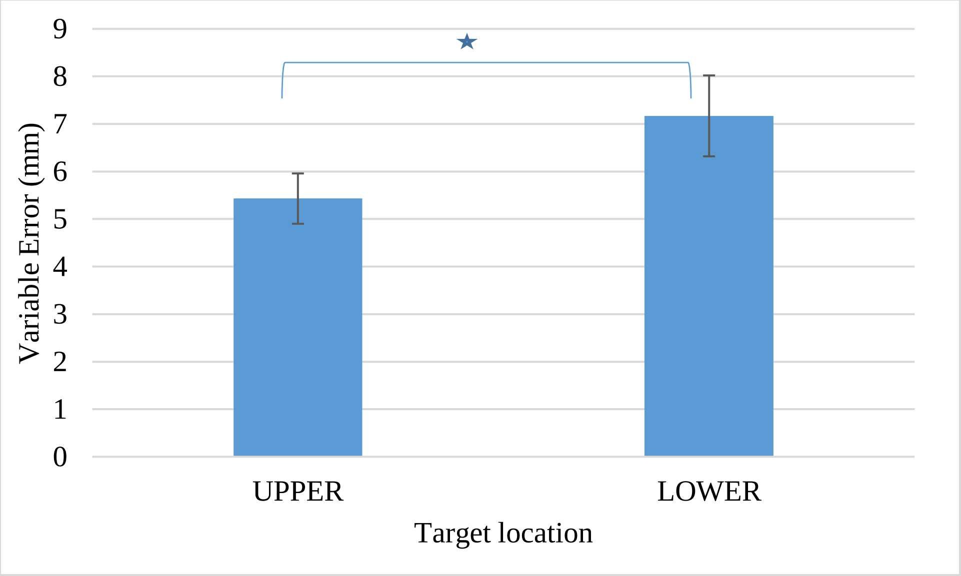

Figure 16: Variable error on the z axis. Error bars show standard error measures. * indicates significant difference (a < 0.05).

Variable error analysis on the x-axis showed no significant effect of condition [F (2, 18) = 0.349, p = 0.71], target location [F (1,9) = 2.204 p = 0.172] and interaction of target location and condition [F (2, 18) = 0.943, p = 0.408]. The mean variable error on the x-axis for each condition is represented in Table 9.

Table 9: Variable error on the x-axis.

Conditions	Mean(mm)	SE	95% Confidence Interval	
			Lower	Upper
No-sound	6.04	0.678	4.5	7.57
Valid	6.24	0.717	4.62	7.86
Invalid	6.11	0.693	4.54	7.67

Movement trajectory analysis

Mean Movement Trajectory. The analysis of movement trajectory as a function of the percentage of MT, showed a significant main effect of target location [F (1,9) = 928.931, p<0.001] and Movement trajectory [F (4,36) =123.906, p<0.001]. There was also a significant interaction between target location and movement trajectory [F (4, 36) =1020.774, p<0.001]. In contrast, there was no significant main effect of condition [F (2,18) =0.316, p= 0.731], no significant interaction between condition and target location [F (2,18) =0.302, p= 0.743] and no significant interaction between condition and movement trajectory [F (8,72) =1.01, p= 0.436]. There was no significant interaction between condition, target location, and Movement trajectory [F (8,72) =0.396, p= 0.919]. Post hoc analysis revealed significant deviations between the upper and lower targets began at 60% of movement (Figure 17).

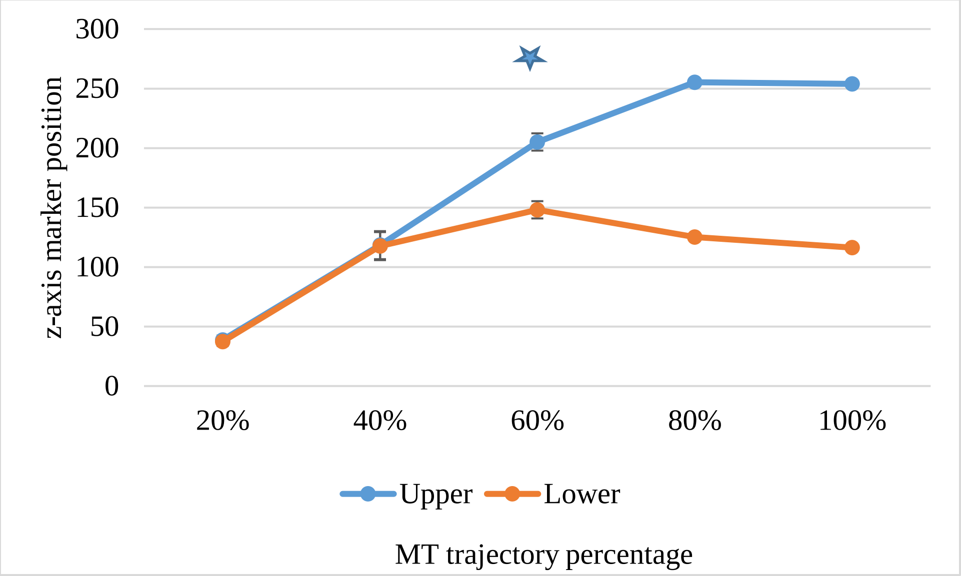

Figure 17: Interaction between mean movement trajectory and percentage movement time point. Error bars show standard error measures. * indicates significant difference (a < 0.05)

For movement trajectory variability in the z-axis showed, there was significant main effect of target location [F (1,9) = 6.262, p= 0.034] and movement trajectory [F (4,36) =27.738, p<0.001]. There was also a significant interaction between target location and Movement trajectory [F (4,36) =2.577, p=0.05] with significant differences in the variability of the trajectory at about 40% of MT (Figure 18). However, there was no significant effect of condition [F (2,18) =0.152, p= 0.86], no significant interaction between condition and target location [F (2,18) =0.216, p= 0.808] and no significant interaction between condition and movement trajectory [F (8,72) =1.79, p= 0.094] There was also no significant interaction of condition, target location, and movement trajectory [F (8,72) =0.725, p= 0.669].

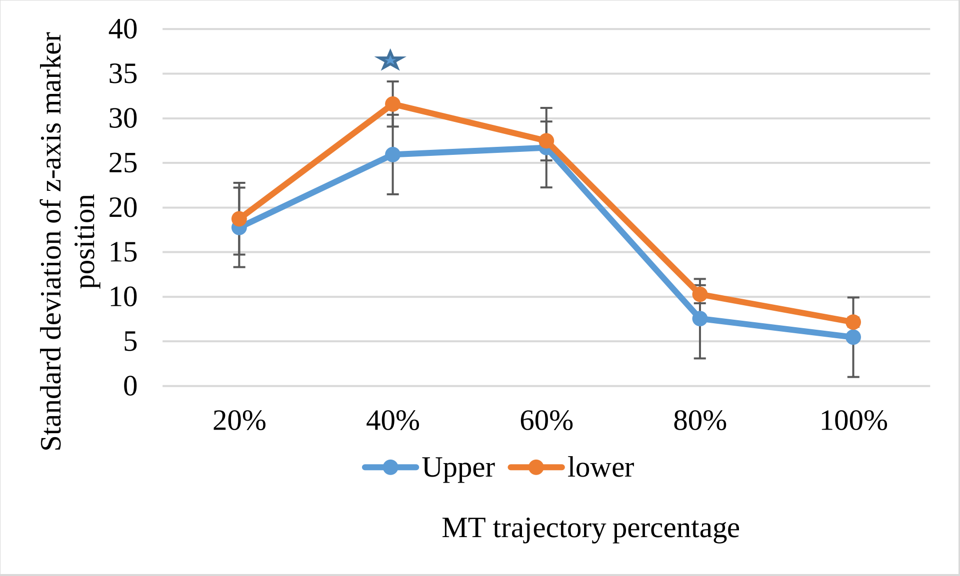

Figure 18: Standard deviation of Movement trajectory as a function of percentage movement time point. Error bars show standard error measures.

Microswitch Reaction time (RT) data analysis

Results from microswitch reaction time data analysis matched with the 30mm/s threshold data

The analysis of reaction time (RT) after matching the data with the Optotrak 30mm/s threshold data showed significant main effect of condition [F(2, 20)= 3.617, p = 0.046]. However, there was no significant main effect of target location [F(1,10)=0.027, p = 0.873] and no significant interaction between target location and condition [F(2,20)= 0.055, p = 0.946]. Post hoc analysis showed significant differences between the no-sound and valid condition with a mean of 273ms and 264ms respectively (Figure 19).

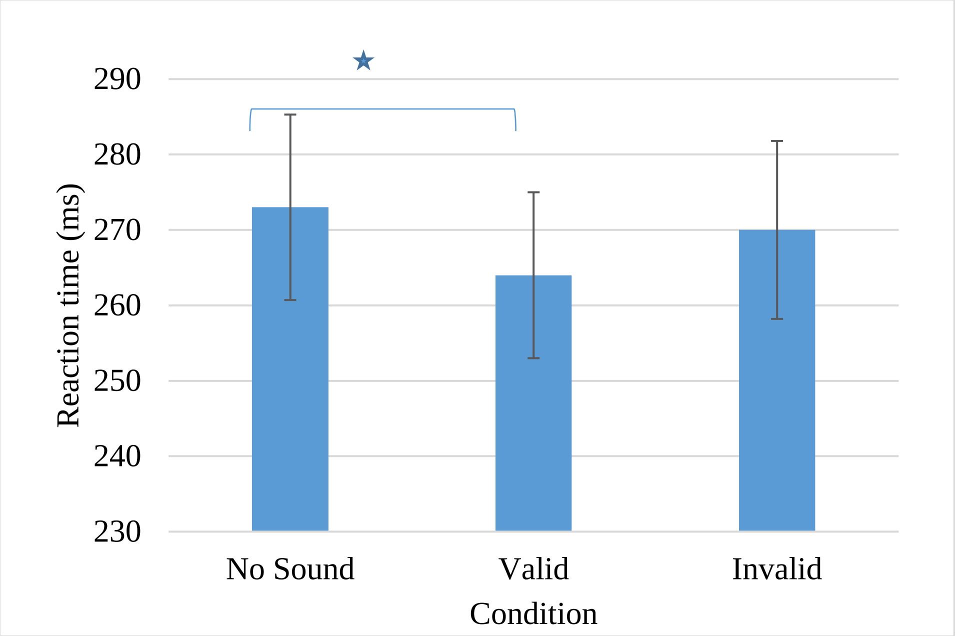

Figure 19: reaction time data matched with the 30mm/s data. Error bars show standard error measures. * indicates significant difference (a < 0.05).

For reaction time variability, There was no significant effect of condition [F(2, 20)= 1.573, p = 0.232], target location [F(1,10)= 0.209, p = 0.657] and no significant interaction between condition and target location [F(2,20)= 0.01, p = 0.990].

Results from microswitch Reaction time data analysis matched with the 15mm/s threshold data

The analysis of reaction time (RT) after matching the data with the Optotrak 15mm/s threshold data showed no significant main effect of condition and target location [F(2, 18)= 0.091, p = 0.913] and F(1,9)=0.007, p = 0.936] respectively (Figure 20). There was also no significant interaction between target location and condition [F(2, 18)= 0.176, p = 0,84].
For reaction time variability, There was no significant effect of condition [F(2, 18)= 0.57, p = 0.577], target location [F(1,9)= 2.23, p = 0.643] and no significant interaction between condition and target location [F(2,18)= 0.94, p = =0.408].

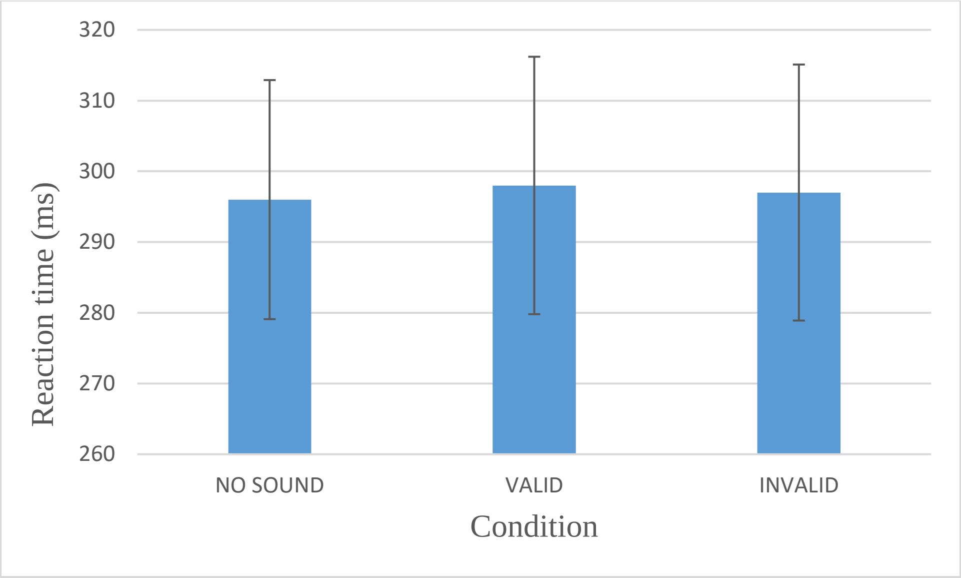

Figure 20: Microswitch reaction time data matched with the 15mm/s data. Error bars show standard error measures.

Summary Table of results

Table 10: Table showing a summary of all the analysis carried out.

Dependent variables	**30mm/s onset and offset Kinematic threshold analysis**	**Microswitch RT data analysis matched with 30mm onset data**	**15mm/s onset and offset Kinematic threshold analysis**	**Microswitch RT data analysis matched with 15mm onset data**
Reaction Time (RT)	Significant main effect of condition [F(2, 20)= 3.519, p<0.05] .Valid condition had significantly shorter RT than No-sound condition. No significant effect of target location or interaction between target location and condition.	Significant main effect of condition [F(2, 20)= 3.617, p = 0.046]. Valid condition had significantly shorter RT than No-sound condition. No significant effect of target location or interaction between target location and condition.	There was no significant main effect of condition [F (2, 18) = 0.228, p = 0.798] or target location [F(1,9= 0.929, p = 0.36]. There was also no significant interaction between target location and condition [F (2, 18) = 0.377, p = 0.691].	There was no significant main effect of condition and target. No significant interaction between target location and condition.
Movement Time (MT)	Significant main effect of target location [F (1,10) =8.863, p = 0.014] with significantly		Significant main effect of condition [F (2, 18) = 5.222, p = 0.016]. Valid condition was	

	longer MT to the upper targets compared to the lower targets. No significant effect of condition or interaction between target location and condition		significantly longer than the no-sound condition. There was no significant main effect of target and no significant interaction of target location and condition	
Percentage Time to peak velocity **%ttPV**	Significant main effect of target location [F(1,10)= 24.747, p<0.001].More time to peak velocity to the upper targets than the lower targets. No significant effect for condition was observed, neither was there a significant interaction between target location and condition.		Significant main effect of target location [F(1,9)= 22.597, p = 0.001]. More time to peak velocity to the upper targets than the lower targets. No significant effect for condition was observed, neither was there a significant interaction between target location and condition.	

Constant Error (CE)	On the z-axis, no significant effect for condition nor target location was observed, neither was there a significant interaction between target location and condition. On the x-axis, there was no significant main effect of condition, target location and interaction between target location and condition.		On the z-axis, no significant effect for condition nor target location was observed, neither was there a significant interaction between target location and condition. On the x-axis, no significant effect for condition nor target location was observed, neither was there a significant interaction between target location and condition.	
Variable Error (VE)	On the z-axis, no significant effect of condition nor target location was observed, however, there was a significant interaction between		On the z-axis, Significant main effect of target location [F (1,9) = 15.275 p=0.004]. Higher variable error observed to the lower targets	

	target location and condition [F (2,20) = 4.18, p = 0.031]. On the x-axis, there was no significant main effect of condition, target location and interaction between target location and condition.		compared to upper targets. No significant main effect for condition and no significant interaction of target and condition on the z-axis. On the x-axis, no significant effect for condition nor target location was observed, neither was there a significant interaction between target location and condition.	
Movement trajectory analysis	Significant main effect of target location [F (1,10) =1221.923, p<0.001] and Movement trajectory [F (4,40) =147.025, p<0.001].		Significant main effect of target location [F (1,9) = 928.931, p<0.001] and Movement trajectory [F (4,36) =123.906, p<0.001].	

	Significant interaction between target location and Movement trajectory [F (4,40) =709.46, p<0.001]. Significant deviations between the upper and lower targets began at about 60% of the movement trajectory. There was significant movement trajectory variability at about 40% of movement trajectory between the upper and lower targets [F (4,40) =4.867, p= 0.003].		Significant interaction between target location and Movement trajectory [F (4, 36) =1020.774, p<0.001]. Significant deviations between the upper and lower targets began at about 60% of the movement trajectory. There was significant movement at about 40% of movement trajectory between the upper and lower targets [F (1,9) = 6.262, p= 0.034].	

Chapter Five

Discussion

It is widely accepted that some attentional processes are automatic and fast while others are voluntary and slow (James, 1890; Posner, 1980; Hanlon et al., 2017; Klein & Ivanoff, 2008; Neyedli & Welsh, 2012; Yeshurun & Tkacz-Domb, 2021). Typically, covert attention has been examined by varying the interval between cue presentation and target presentation and indeed, these studies have shown that endogenous spatial attention requires about 300ms from the target onset for maximal effects to be reached while exogenous spatial attention requires a shorter amount of time at 100ms to reach maximal effect (Yeshurun & Tkacz-Domb, 2021). The current thesis sought to determine the effects of congruency (validity) of endogenous auditory stimuli on reaching performance to multiple targets by evaluating performance measures (reaction and movement time) and kinematic variables such as movement trajectory. We also looked at how endogenous auditory cues affected the spatial averaging behaviour of participants when moving to multiple targets as reported in previous studies (Chapman et al. 2010). Spatial averaging behaviour is observed when participants are confronted with a choice to reach to multiple targets and they initially move to the middle of all potential target locations before redirecting to the actual target location in other to rapidly and more efficiently reach the target goal. Overall, humans use different strategies to move depending on whether the available information and if the cues are endogenous or exogenous (Spence & Driver, 1994; Van der Stoep, Van der Stigchel, & Nijboer, 2015).

For the present study, the initial data analysis of the three-dimensional displacement data used an onset and offset velocity threshold of 30mm/s for 30ms. The results for reaction time using this threshold revealed a significant effect of condition such that the valid condition was shorter and faster than the no-sound condition. This result did not follow our prediction as the presentation of the auditory cue came immediately after movement initiation (which demarcates the end of the reaction time phase of movement to a target location). Hence logically, we were not expecting to find an effect of condition on reaction time as all the conditions had the same go signal to initiate the reaching movement. This unpredicted result reported in the analysis with the 30mm/s threshold prompted us to re-evaluate the velocity threshold set in our definition of movement initiation due to the possibility that we were already capturing effects of the cue condition on movement time in the reaction time analysis. We, therefore, reanalyzed the data with a 15mm/s threshold to mitigate this issue.

According to our predictions, we expected to see an effect of the endogenous auditory cue condition on movement time due to the information properties embedded in the auditory cue presented after participants initiated their movement. We predicted the valid cues would positively affect temporal attention as reported in results from previous studies that have shown that endogenous cueing had the potential to positively influence temporal and spatial attention and thus movement performance (Roberts et al., 2009; Yeshurun & Tkacz-Domb, 2021). However, in the studies that reported this temporal attention effect of endogenous attention, the time between the presentation of the endogenous cue to the presentation of target (i.e., the stimulus onset asynchrony (SOA)) were usually varied with maximal effect of the endogenous cue occurring at about 300ms, which is in agreement with the expected time for maximal effect in spatial attention (Roberts et al., 2009; Griffin, Miniussi & Nobre, 2001; Muller & Rabbitt, 1989). For example, the results of the experiment by Roberts and colleagues in 2009 showed that for endogenous auditory cue to have a beneficial influence on movement response, participants required an SOA of more than 450ms, as endogenous auditory cueing appeared to be a slow process requiring longer SOA for the information embedded to be beneficial in the task. Their result supports the results reported in our study where we had no significant effect of auditory cue condition on MT because we did not include an SOA in our experimental design and presented the auditory cue at the same time we presented the visual target, this resulted in the no-sound, valid and invalid conditions having a mean MT of 672ms, 683ms and 672ms respectively. We did observe a significant effect of target location with MTs to the lower targets occurring faster than movements to the upper targets. It is important to note that in our experimental design, the presentation of the auditory cue occurred at the same time as the presentation of the target location; hence the SOA was 0ms. Thus, in the scenario where the target was identified concurrently with the auditory cue, there did not appear to be any impact on the movement time.

The percentage time to peak limb velocity (%ttPV) analysis showed that ttPV occurred earlier in the movement trajectory when participants moved to lower targets (about 30% of MT), compared to when moving to the upper targets (which occurred at about 44% of MT). With regards to reaching accuracy, the auditory condition and target location had no significant effects on both constant and variable error. Thus, our results showed that performance across all three conditions was similar when moving to the targets located at the upper and lower part of the screen. This result for endogenous auditory cues is also inconsistent with previous studies that reported better accuracy with valid endogenous cues in visual tasks (Stein et al., 1989).

In terms of trajectory deviations, spatial averaging behaviour was observed at about 60% of movement time, as participants initially moved in the middle of the four potential final target locations. This spatial averaging strategy was done because of the uncertainty of the final location of the target. This observation is consistent with previous studies (Chapman et al., 2010; Stewart, Gallivan, Baugh, & Flanagan, 2014; Welsh & Elliott, 2004) whereby when presented with competing multiple targets, participants adopted the spatial averaging technique before correcting their movement to the intended target location. Using the idea of Elliott and Khan (2010), the spatial averaging strategy ensures that participants could home-in on the correct target location, among the potential distractors, with minimal energy expenditure.

The analysis of movement time data with the 15mm/s movement onset velocity revealed a significant negative effect of endogenous auditory condition such that the MT in the was the shortest amongst the three conditions. More specifically, the valid condition was significantly longer MT than the no-sound condition. Although the invalid condition was not statistically significant when compared to the no-sound condition, it also had a higher MT. This result did not follow what was initially predicted, which was that the valid condition would have the shortest MT given an adequate SOA. A possible explanation for this observation is that the presentation of the information containing the endogenous auditory cue at the same time with the presentation of target location led to an attentional overload similar to that seen when dual-tasking, whereby the brain with its limited attentional capacity is tasked with interpreting the spatial information embedded in the endogenous auditory cue presented at the same time as the visual target location to be reached while deciding to move to the target presented (Carrasco, 2011; Hommel et al., 2019; Macaluso & Doricchi, 2013). This added perceptual decision process, which is lacking in the no-sound condition, could have actively led to the increase in MT in the conditions with the endogenous auditory cue present (valid and invalid conditions) as opposed to the no-sound condition. According to Muller & Rabbit, 1989, endogenous orienting is subject to interruption by subsequent visual events. Since both the visual target and endogenous auditory cue were presented at the same time, there might have been an interruption in the speed of processing and interpretation of the information presented in the auditory cue. Moreover, because the design of this study had not included an SOA, as opposed to the recommended SOA of over 300ms needed for the maximal positive effect of endogenous cueing (Spence & Driver, 1994; (Spence & Driver, 1997). Therefore we observed an adverse effect of the endogenous auditory cue on movement time.

In contrast to RT and MT, percentage time to peak limb velocity (%ttPV) followed a similar pattern observed in the initial analysis with 30mm/s velocity onset. Specifically, relative time to peak velocity to the lower targets occurred earlier (at about 31% of MT) in comparison to the upper targets (at about 42 % of MT). In contrast to our predicted hypothesis, there was no significant effect of condition on %ttPV. Overall, all auditory conditions reached peak velocity at similar relative times. Relative ttPV only depended on whether participants were aiming to upper or lower targets.

With respect to spatial accuracy, there was no significant effect of condition or target location on constant error values. This contrasts with our hypothesis whereby we expected an effect of condition on the endpoint error. Specifically, we predicted that valid conditions would have smaller errors due to the target location presented being congruent with the available auditory cue, thus guiding movement for the correct selection of the target. With regards to variable error, analysis showed that participants were more consistent when moving to upper targets and displayed more variability when reaching to lower targets in the z-axis. This pattern was not observed for variable error on the horizontal x-axis. The variability to upper targets can be explained by the effect of gravity working against movements to upper targets as explained by Elliot et al., 2001.

Results from the trajectory analysis with the 15mm/s velocity onset threshold were similar to what we observed in the initial analysis using 30mm/s velocity onset. That is, participants always made use of spatial averaging when reaching to multiple potential target locations. In the present experiment, participants were moving to 4 potential targets. The finding of a spatial averaging strategy is consistent with previous studies that support the idea of parallel preparation of multiple motor programs (Cisek, 2007: Chapman et al., 2010; Stewart, Gallivan, Baugh, & Flanagan, 2014; Welsh & Elliott, 2004; McPeek & Keller, 2004) and that the suppression of unwanted motor programs of distractor targets is a function of time (Chapman et al., 2010). This means that spatial averaging would most likely not be observed if there was enough time to suppress motor programs to the other potential targets/distractors or if there was prior knowledge of where the target was to appear. But in our experimental design, there was no time for participants to suppress other motor plans to the four targets presented, therefore in order to accurately reach to the target location, participants aim to the center of the targets which brings them closer home to the four targets presented before accurately home-in in the correct target thereby minimizing energy expenditure (Elliott and Khan, 2010; Elliot et al., 2010).

In addition to the analysis of movement trajectory, we analyzed the RT of the microswitch embedded in the table recorded by the Eprime software from which participants initiated their movement. This data was matched to the kinematic data analyzed in the 30mm/s velocity onset and the results were identical to the results obtained from kinematic analysis whereby there was an effect of condition on RT. In order to investigate the possibility that we were capturing initial MT in our analysis of RT during the 30mm/s movement onset and offset velocity threshold, we decided to do a reanalysis of the data set by reducing the movement onset and offset velocity from 30mm/s to 15mm/s. The results of this reanalysis indeed captured the expected effects of our experimental design, including the expectation of endogenous cue congruency on movements to multiple targets. Specifically, the analysis of reaction time data under this newly decreased movement onset velocity threshold revealed no significant effect of condition. The lack of effect on RT was expected because the presentation of the auditory cue occurred after RT. There was also no significant effect of target location on the RT time with all conditions in the upper and lower target location having almost identical mean reaction times of 251ms, 249ms and 252ms in the No-sound, Valid and Invalid condition respectively.

Summary

In summary, the current findings in this study failed to provide support for the benefits of endogenous auditory cues when reaching to multiple targets, specifically when the cue and target are presented at the same time. In other words, the lack of SOA greater than 300ms needed to achieve the maximum benefits of an endogenous auditory cue integrated into the movement plan to achieve the best performance (Yeshurun & Tkacz-Domb, 2021; Spence & Driver, 1994) in our experimental design led to negative effects of the endogenous auditory cue on movement time performance in our study. Our results showed that the presence of an endogenous auditory cue influences the speed at which movement to a target is performed whether or not adequate SOA was provided. Ideally, the provision of an SOA of 300ms or more is needed for movement performance to benefit maximally from the effect of endogenous auditory cue congruency. We also observed that participants adopted the use of spatial averaging regardless of cue validity and always tried to maximize accuracy and speed by adopting the spatial averaging behaviour. These results suggest that the validity of an endogenous auditory cue does not bias the movement trajectory. However, this contrasts past studies in which valid exogenous auditory cues biased movement trajectory via an automatic attentional capture and earlier movement deviations.

Limitations

The sample size was limited by the inability to collect more participant data due to restrictions related to in-person research as a result of the Covid-19 pandemic. The relatively small sample size analyzed may have influenced the results reported. In particular, there was a trend for the Invalid Condition to have longer MTs relative to the No-sounds condition; however, this difference was not statistically significant with the current analysis. Additional data would have buffered for the data that were excluded at different stages of the raw data processing as well as higher trial-to-trial variability in the Invalid condition.

Future directions

Future studies should vary the length of SOA in other to further investigate the effect of endogenous auditory cueing on reaching to visual targets. The current project had a 0ms SOA from the presentation of the auditory cue and presentation of the target location. For example, having endogenous auditory cues presented to participants at 100ms, 300ms and 500ms before the display of target location would provide a thorough examination of the priming effects of the endogenous auditory cues by assessing different time courses for the central nervous system to process the cues.

The current study made use of tone frequency to provide information about the final target location. Newer advances in audio files include the advent of spatial audio files, which could evoke the perception of the spatial location of the sound. That is the addition of depth and distance to audio files e.g., Spatial 8D audio. This study can be replicated, and target location can be varied between audio and visual targets to investigate further the effect of having information embedded in sound. For the most part, there has been no study that has investigated the effect of such audio cues due to the newness of this auditory concept.

Conclusion and Implications

To conclude, the findings in this current thesis is important if we think about the designs of mobile and automobile technology which incorporates highly sophisticated in-car technology such as warning signals and navigation systems, resulting in the constant influx of auditory and visual information. The importance of knowing more about how this stream of auditory information may affect performance, which is primarily a visual task, cannot be overemphasized. The results from this imply that when designing these machines, it is advisable to consider having endogenous auditory cues occurring at least 300ms earlier than visual cues to prime the user to a target location in other to benefit maximally from the availability of such cues.

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Appendix A

RENEWAL APPROVAL

Date: **November 6, 2020** **New Expiry: November 16, 2021**

To: **Cheryl Glazebrook**
Principal Investigator

From: **Zana Lutfiyya, Chair**
Education/Nursing Research Ethics Board (ENREB)

Re: **Protocol # E2018:089 (HS22295)**
Multisensory-motor Integration: The Impact of Sight and Sound on Reaching Movements

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Education/Nursing Research Ethics Board (ENREB) has reviewed and renewed the above research. ENREB is constituted and operates in accordance with the current *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans.*

This approval is subject to the following conditions:

i. Any modification to the research must be submitted to ENREB for approval before implementation.
ii. Any deviations to the research or adverse events must be submitted to ENREB as soon as possible.
iii. This renewal is valid for one year only and a Renewal Request must be submitted and approved by the above expiry date.
iv. A Study Closure form must be submitted to ENREB when the research is complete or terminated.

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Appendix B

INFORMED CONSENT

Multisensory-motor Integration: The Impact of Sight and Sound on Reaching Movements

Principal Investigator: Dr. Cheryl Glazebrook
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This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

PURPOSE: We are interested in learning visual attention and spatial arrangement affects movement planning processes when reaching to multiple targets.

DESCRIPTION: During the study, you will be asked to make a series of pointing movements to target in front of you. An OPTOTRAK 3-D motion analysis system will be used to record your hand movement. Prior to this task, you will be asked to fill out a brief demographics questionnaire that inquires about your age, gender, handedness, and whether or not your vision and hearing are corrected (glasses, contact lenses, hearing aids). The whole procedure will take 60minutes to complete.

RISKS AND BENEFITS: There are no evident risks inherent in the tasks you will perform. Some of the tests may become repetitive and you may experience boredom and/or mild muscle fatigue in your arms. While this may be frustrating, the investigator with you will provide breaks throughout and you may request a break at any time.

Your participation in this study will help us to investigate the role or impact of auditory attention when planning movement to potentially competing targets.

COSTS AND PAYMENTS: There are no fees or charges to participate in this study. However, you will receive a small honorarium for your participation.

CONFIDENTIALITY: Your information will be kept confidential. Once you begin the study your name, information, and results will be referred to by a code number. All files containing identifying information will be stored in a locked cabinet separate from data with your code number. Your files will only be accessible by the investigators and will be destroyed by Dr. Glazebrook seven years after the completion of the study (approximately June, 2026). All papers containing personal information will be shredded. All electronic files will be deleted. Any CDs or DVDs containing data will be physically destroyed. Only Dr. Cheryl Glazebrook and the student research assistants listed will have access to any lists that contain identifying information.

DEBRIEFING: Upon completion of the study the experimenter will describe the research questions being considered. If the participant would like to know the results of the study please indicate ‘yes’ on the consent form where indicated and the student research assistant will contact you with a summary of the findings in approximately 4 months.

VOLUNTARY CONSENT: If the participant *does not wish to participate* in the study or wishes withdraw from the study, you are free to leave without consequence at any point in time and we thank you for your consideration.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you choose to withdraw from the study you will still receive compensation for the time you have participated. The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

A copy of this consent form has been given to you to keep for your records and reference.

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122 or humanethics@umanitoba.ca.

INFORMED CONSENT

Research Study: Multisensory-motor Integration: The Impact of Sight and Sound on Reaching Movements

Name of Participant (Please Print)________________________________ Date____________

Signature of Participant____ Date ____________

Researcher/ Delegate's Signature __________________________________Date ___________

SUMMARY OF FINDINGS: Would you like to be contacted by a student research assistant with a summary of the overall findings of this study? ☐ YES ☐ NO

If yes, please complete the following:

Name: ____

Phone Number: ____

Email Address: ____

Appendix C

Demographics Questionnaire

Participant Number: ________________________________

Age of Participant: ______________ Gender:______________________

Dominant Hand (check one): Right ☐ Left ☐

Vision (check one): Normal ☐ Corrected to Normal (contact lenses/eyeglasses) ☐

Hearing (check one): Normal ☐ Corrected to Normal (hearing device) ☐

Is there any history of neurological or orthopaedic injury in the last year? Yes ☐ No ☐

Is there any history of neurological or orthopaedic surgeries in the last year? Yes ☐ No ☐